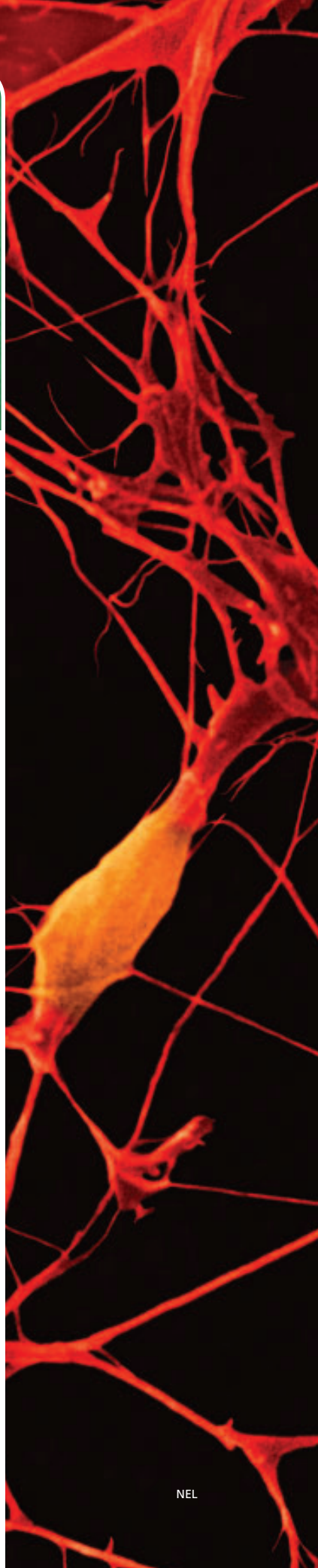
unit

30 A Nervous and Endocrine Systems



Organs do not work independently; rather, they work in coordinated systems that continuously respond and adjust to changing environments. The nervous system senses changes in the internal and external environment, and relays this information through neurons, such as those shown here. The body then responds to these messages. In many cases, it is the endocrine that responds, by changing levels of hormones.

Researchers are investigating artificial substitutes for many human organs and cells. Artificial cells that mimic the biological processes of natural cells could one day be used to help build artificial kidneys and livers. Synthetic fabric could temporarily serve as artificial skin for burn victims. A bioartificial pancreas that is currently being tested in animals at the University of Alberta could one day provide a cure for diabetes. To be able to function properly, an artificial organ must also be able to communicate with and act together with the body's own cells. What characteristics do these substitutes need to function effectively in the body? In this unit, you will study how the nervous and endocrine systems work together to coordinate the functions of all the organs of the body and help maintain homeostasis, the body's attempt to adjust to a fluctuating external environment.

As you progress through the unit, think about these focusing questions:

- How does the human body maintain equilibrium between its internal and external environments?
- What physiological processes and control systems are involved in maintaining homeostasis?

UNIT 30 A PERFORMANCE TASK

Determining the Effects of Caffeine on Homeostasis

Caffeine is one of the world's most widely used drugs. In this Performance Task, you will investigate the effects caffeine has on human systems and demonstrate how the homeostatic feedback adjustment works. You will use an invertebrate or a protist as a model to provide information that may be applicable to human physiological systems. At the end of this unit, you may apply your skills and knowledge to complete this Performance Task.

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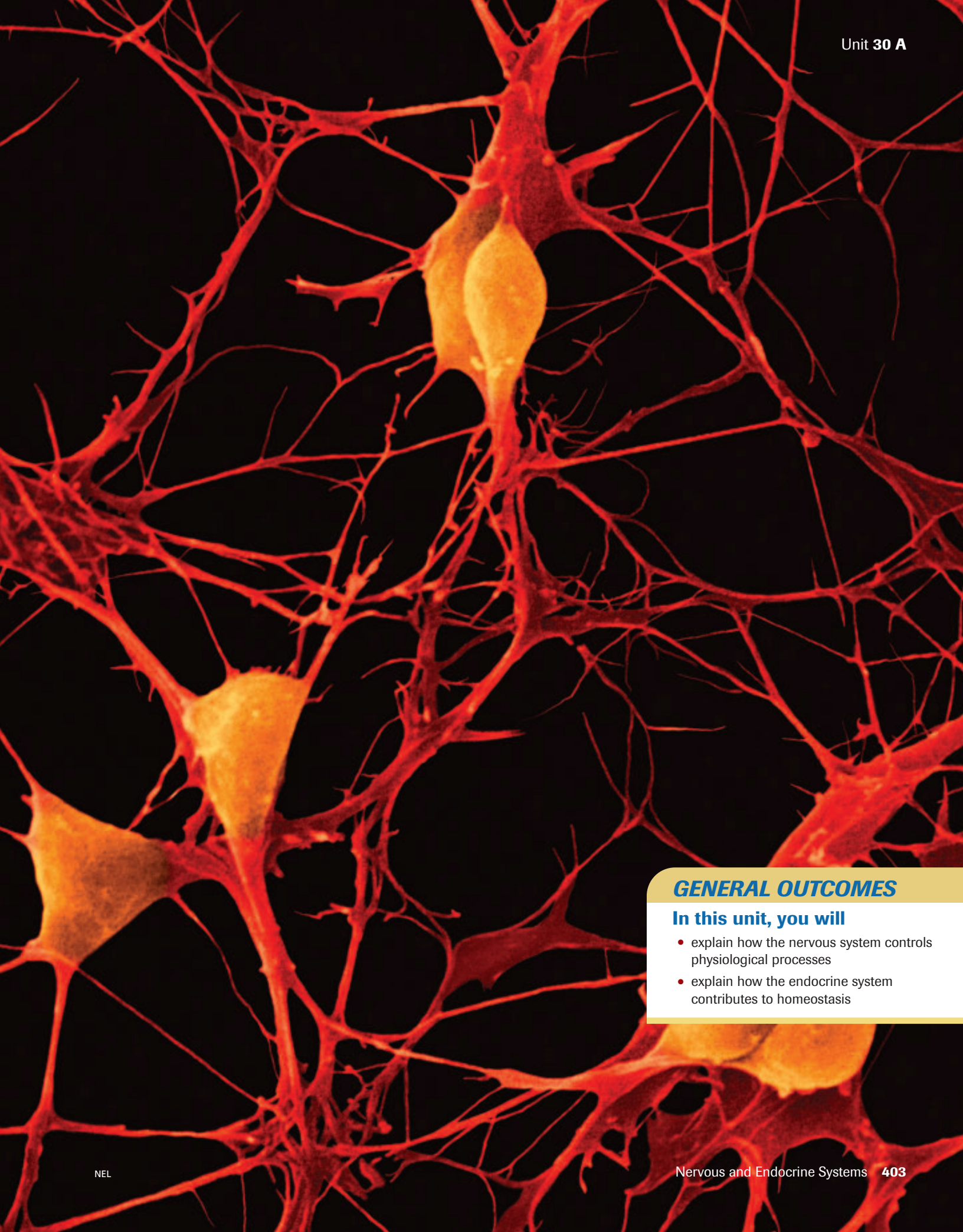

GENERAL OUTCOMES

In this unit, you will

- explain how the nervous system controls physiological processes
- explain how the endocrine system contributes to homeostasis

Unit 30 A
Nervous and Endocrine Systems

ARE YOU READY?

These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

Prerequisites

Concepts

- cellular structures and functions
- kidney function
- immune response

Skills

- ask questions about observed relationships
- plan investigations of questions, ideas, and problems
- analyze data and apply mathematical concepts and conceptual models to develop and assess possible solutions

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

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Knowledge

1. Place the following terms from smallest to largest and provide an example of each term:
   - chromosome
   - tissue
   - organ system
   - cell
   - gene
   - organ

2. Which statement is the best description of negative feedback?
   (a) A series of receptors that respond to changes in the internal environment of the body by inhibiting the release of hormones.
   (b) A control system that prevents imbalances in the body by compensating for any changes with a new change in the opposite direction.
   (c) A mechanism that responds to changes in the internal and external environments of the body by stimulating the release of hormones.
   (d) A biological system that prevents the body from responding to changes in the external environment, releasing hormones, or using nerves to shut down organs.

3. Use the diagram of negative feedback in **Figure 1** to explain how the body maintains homeostasis when water intake decreases. (*Hint:* The excretory system was covered in your Biology 20 studies.)

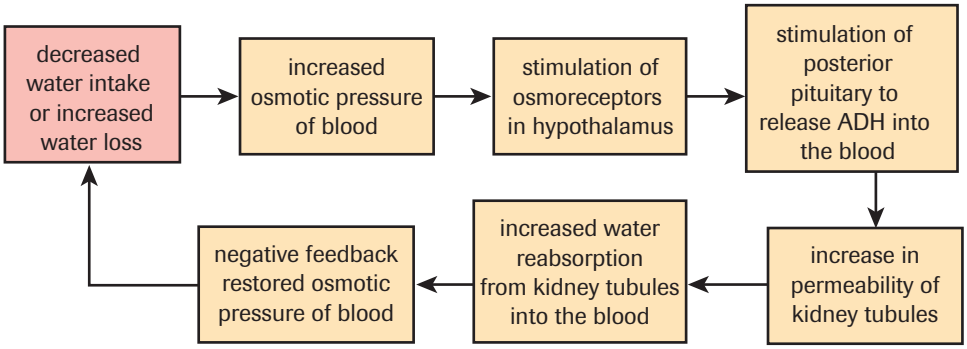

Figure 1

4. From the physiology you studied in Biology 20, provide an example of how cells communicate with each other to protect the body from invading microbes.

5. From the physiology you studied in Biology 20, provide an example of how cells in one part of the body communicate with cells in another part of the body to release hormones.

Skills and STS Connections

6. A cell is placed in a beaker and the concentration of Na^+ ions and sugar ($C_6H_{12}O_6$) is monitored after 10 s and 60 s (**Figure 2**).
   (a) By examining both the cell and the beaker after 10 s, what evidence supports the hypothesis that the cell membrane is permeable to sugar?
   (b) By examining both the cell and the beaker after 10 s, what evidence supports the hypothesis that Na^+ ions move by diffusion?
   (c) By examining both the cell and the beaker after 60 s, what evidence supports the hypothesis that sugar is actively transported?
   (d) By examining both the cell and the beaker after 60 s, provide a hypothesis that helps explain why the total number of sugar molecules has decreased.

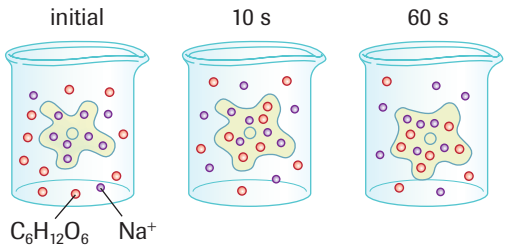

Figure 2

7. A research team wishes to show the negative effects of consuming alcohol on driving. Knowing that alcohol impairs reaction times, the researcher needs to design an investigation that will test their hypothesis.
   (a) Create a hypothesis for the experiment.
   (b) Present the experimental design.
   (c) Write a multi-step procedure for the experiment.
   (d) Identify the independent and dependent variables for the experiment.
   (e) What variables must be controlled to get reliable results?
   (f) Design a data table for the experiment.
   (g) Would you expect identical data from different subjects? Explain your answer.
   (h) What practical information could be provided by the experiment?

chapter

13 Nervous System

In this chapter

In 1998, Michael J. Fox (**Figure 1**) announced that he was leaving a popular television sitcom because of Parkinson's disease. Fox was diagnosed with early stages of Parkinson's disease in 1991, when he noticed a twitch in a finger. Over the next seven years the disease progressed, making acting very difficult.

Parkinson's disease is a progressive degenerative nerve disorder that affects muscle activity. Cells in two areas of the brain, the substantia nigra and the locus cerulus, degenerate and die. These cells secrete dopamine and norepinephrine. Any reduction in these chemicals affects muscle movement. Early symptoms include muscle tremors, slow body movements, rigidity in the joints, and an inability to regain one's balance. As the disease progresses, the symptoms become more pronounced and daily activities become extremely difficult.

The cause of the disease is not known. In about 15 % of cases, heredity plays a role. A person can inherit one of two genes that produce proteins that destroy the brain cells. In the remaining 85 % of cases, scientists believe that a dormant gene is triggered. Unfortunately, the actual trigger and how the gene is triggered is unknown. Although the disease usually occurs in people over 50, Parkinson's can also affect younger adults.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Do nerves carry electrical current? Explain.
2. Does a nerve that carries information from your eye, function any differently from a nerve that sends information to a muscle?
3. A woman touches a hot object and quickly moves her finger away. Does the brain coordinate the movement of the finger away from the hot object?
4. A cougar jumps from behind a bush and startles a man standing nearby. The information is passed to the man's brain. Explain how the nervous system, endocrine system, and urinary system prepare his body for stress.
5. Endurance athletes, such as Alex Decoteau (**Figure 2**, next page), a great long-distance runner from the Red Pheasant reserve in Saskatchewan, have to endure a lot of pain. He was able fight back the pain and win four races in one day. What allows one person to withstand more pain than another person?

Career Connections:
Mental Health Worker; Chiropractor

Figure 1
Canadian actor Michael J. Fox

Figure 2
In 1910, Alex Decoteau won the half-mile, one mile, two mile, and five mile races at a meet in Fort Saskatchewan.

Exploration — Stimulus and Response in Invertebrates

Invertebrates such as worms and leeches have a distinct top and bottom, front and back, and head and tail. In this activity, you will observe the response of an invertebrate to a simple stimulus.

Materials: medicine dropper, invertebrate, microscope slide, paper towel

- Gently touch the head of the invertebrate with a piece of paper towel and note its response.
  (a) Explain why the invertebrate responded as it did.
  (b) What can you infer about the nervous system of the invertebrate?
  (c) How do you think an invertebrate would respond to a concentration of salt added to its environment?

13.1 The Importance of the Nervous System

Prisoners have often been isolated and placed in dark rooms as a means of punishment. Imagine how you would be affected if you didn't know whether it was day or night, or if you couldn't hear a sound for days.

Even in these extreme conditions, however, your nervous system remains active. Information about your depth of breathing, the physical condition of the breathing muscles, and the amount of water contained in the respiratory tract is continually relayed to the brain for processing and storage. Other nerve cells detect air temperature, light intensity, and odours. Pressure receptors in the skin—known as baroreceptors—inform you of the fit of your clothes and can detect an insect scurrying across your leg. Blinking your eyes or scratching your nose requires coordinated nerve impulses. Memories of happy times and hopes for your future reside in the nervous system.

The nervous system is an elaborate communication system that contains more than 100 billion nerve cells in the brain alone. That number exceeds the number of visible stars in the Milky Way galaxy.

central nervous system (CNS) the body's coordinating centre for mechanical and chemical actions; made up of the brain and spinal cord

peripheral nervous system (PNS) all parts of the nervous system, excluding brain and spinal cord, that relay information between the central nervous system and other parts of the body

Organization of the Nervous System

The nervous system has two main divisions: the **central nervous system (CNS)** and the **peripheral nervous system (PNS)** (**Figure 1**). The central nervous system consists of the nerves of the brain and spinal cord and acts as a coordinating centre for incoming and outgoing information. The peripheral nervous system consists of nerves that carry information between the organs of the body and the central nervous system.

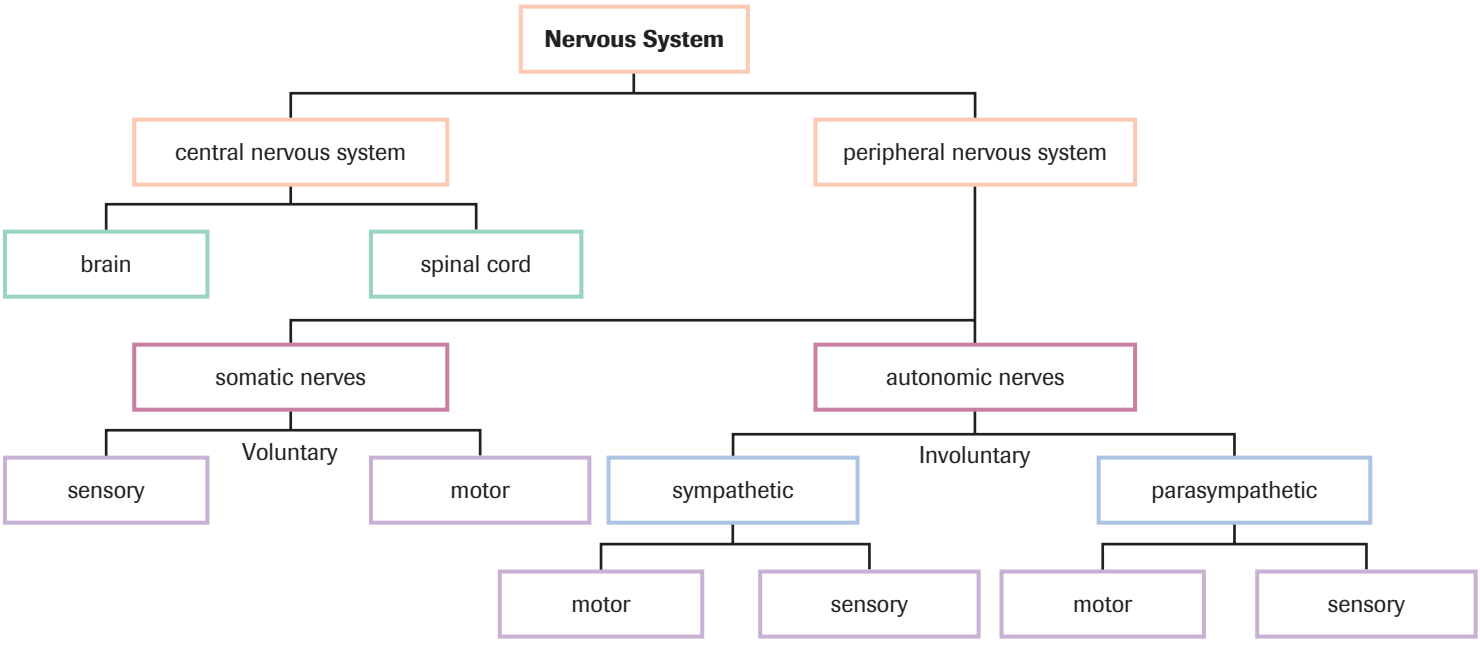

Figure 1
The main divisions of the nervous system

The peripheral nervous system can be further subdivided into somatic and autonomic nerves. The somatic nervous system controls the skeletal muscle, bones, and skin. Sensory somatic nerves relay information about the environment to the central nervous system, while motor somatic nerves initiate an appropriate response. The autonomic nervous system contains special motor nerves that control the internal organs of the body. The two divisions of the autonomic system—the sympathetic nervous system and the parasympathetic nervous system—often operate as "on–off" switches. These two systems will be discussed later in the chapter.

Anatomy of a Nerve Cell

Two different types of cells—glial cells and neurons—are found in the nervous system. **Glial cells**, often called neuroglial cells, are nonconducting cells and are important for the structural support and metabolism of the nerve cells. **Neurons** are the functional units of the nervous system (**Figure 2**). All neurons contain dendrites, cell bodies, and axons. The **dendrites** receive information, either from the environment or from other neurons. Like all living cells, neurons contain a nucleus (in a neuron, the nucleus is within the cell body). Dendrites conduct nerve impulses toward the cell body. An extension of cytoplasm, called the **axon**, conducts nerve impulses away from the cell body. A neuron has only one axon, though it may form many branches. In humans, the axon is extremely thin; more than 100 axons could be placed inside the shaft of a single human hair. The axon carries the nerve impulse toward other neurons or to effectors. A close examination of most nerves shows that they are comprised of many axons held together by connective tissue (**Figure 3**, next page).

glial cell nonconducting cell important for structural support and metabolism of the nerve cells

neuron nerve cell that conducts nerve impulses

dendrite projection of cytoplasm that carries impulses toward the cell body

axon extension of cytoplasm that carries nerve impulses away from the cell body

Many axons are covered with a glistening white coat of a fatty protein called the **myelin sheath**, which acts as insulation for the neurons. Axons that have a myelin covering are said to be myelinated. Formed by special glial cells called **Schwann cells**, the myelin sheath insulates by preventing the loss of charged ions from the nerve cell. The areas between the sections of myelin sheath are known as the **nodes of Ranvier**. Nerve impulses jump from one node to another, thereby speeding the movement of nerve impulses. Not surprisingly, nerve impulses move much faster along myelinated nerve fibres than nonmyelinated ones. The speed of the impulse along the nerve fibre is also affected by the diameter of the axon. Generally, the larger the diameter of the axon, the faster the speed of the nerve impulse.

myelin sheath insulated covering over the axon of a nerve cell

Schwann cell special type of glial cell that produces the myelin sheath

nodes of Ranvier regularly occurring gaps between sections of myelin sheath along the axon

All nerve fibres found within the peripheral nervous system have a thin outer membrane called the **neurilemma**, which surrounds the axon. The neurilemma is formed by the Schwann cells and promotes the regeneration of damaged axons. This explains why feeling gradually returns to your finger following a paper cut—severed neurons can be rejoined. However, not all nerve cells that have a myelin sheath have a neurilemma. Nerves within the brain that contain myelinated fibres are called white matter because the myelinated axons are whitish in appearance. Other nerve cells within the brain and

neurilemma delicate membrane that surrounds the axon of some nerve cells

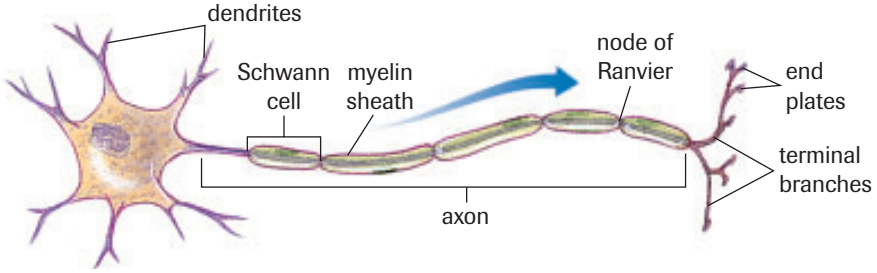

Figure 2
Structure of a neuron. The arrow shows the direction in which a nerve impulse travels.

DID YOU KNOW ?

Multiple Sclerosis

Multiple sclerosis is caused by the destruction of the myelin sheath that surrounds the nerve axons. The myelinated nerves in the brain and spinal cord are gradually destroyed as the myelin sheath hardens and forms scars, or plaques. This scarlike tissue prevents normal impulse transmission. Often referred to as MS, multiple sclerosis can produce symptoms of double vision, speech difficulty, jerky limb movements, and partial paralysis of the voluntary muscles. First identified by a French neurologist in 1868, MS is the most common neurological disease affecting young adults in Canada.

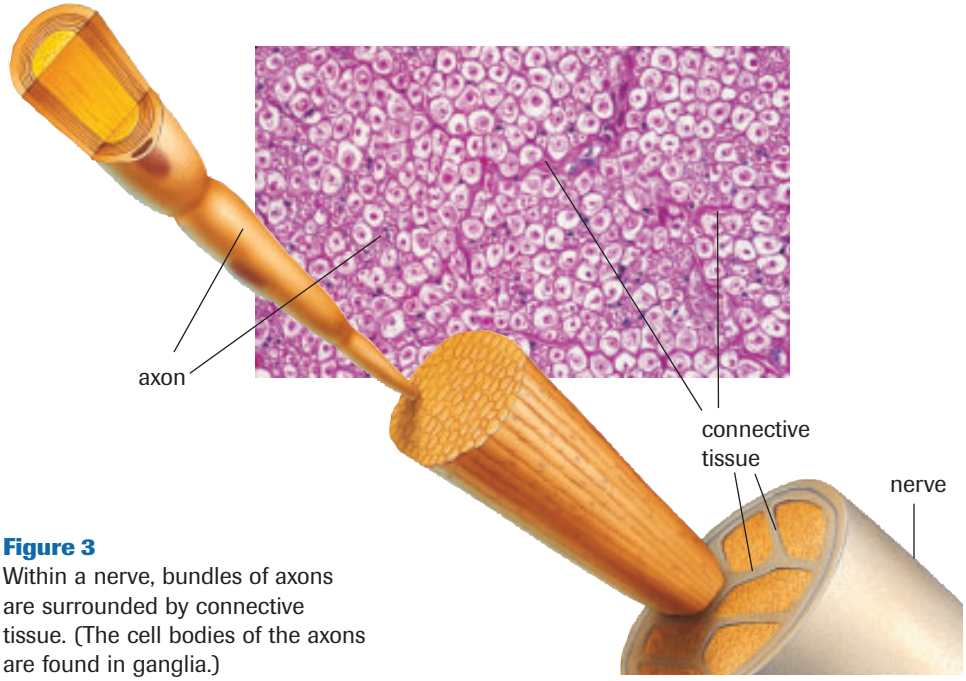

Figure 3
Within a nerve, bundles of axons are surrounded by connective tissue. (The cell bodies of the axons are found in ganglia.)

sensory neuron neuron that carries impulses to the central nervous system; also known as afferent neuron

sensory receptor highly modified dendrites of a sensory neuron that are activated by an environmental stimulus

ganglion (plural **ganglia**) collections of nerve cell bodies located outside the central nervous system

interneuron a neuron of the central nervous system that connects with sensory, motor, and other interneurons to integrate sensory input with motor output; also known as association neuron

motor neuron neuron that carries impulses from the central nervous system to an effector; also known as efferent neuron

effector a cell or organ that produces a physiological response when stimulated by a nerve impulse

spinal cord, referred to as the grey matter, lack a myelin sheath. Cells of the white and grey matter of the central nervous system lack neurilemmas. That is why damage to the central nervous system tends to be permanent.

Neurons are categorized into three groups: the sensory neurons, interneurons, and motor neurons. **Sensory neurons** (also known as afferent neurons) relay information (or stimuli) received by **sensory receptors** about the external or internal environment to the central nervous system for processing. The cell bodies of sensory neurons are located in clusters called **ganglia** (singular, **ganglion**) located outside of the spinal cord.

Interneurons, as the name suggests, link neurons to other neurons. Found only in the brain and spinal cord, the interneurons (also known as association neurons) integrate and interpret the sensory information and connect sensory neurons to outgoing motor neurons. **Motor neurons** (also known as efferent neurons) relay information to the **effectors**, which is the cell or organ that responds to the stimulus. Muscles, organs, and glands are classified as effectors because they produce responses.

Practice

1. Differentiate between the peripheral nervous system (PNS) and central nervous system (CNS).
2. Differentiate between sensory nerves and motor nerves.
3. Briefly describe the function of the following parts of a neuron: dendrites, myelin sheath, Schwann cells, cell body, and axon.
4. What is the relationship between the speed of a nerve impulse and the size of the axon along which it travels?

Repairing Damaged Nerves

For years, scientists have been puzzled about why the central nervous system does not support nerve growth in the same way as the peripheral nervous system. New surgical procedures, the identification of factors that inhibit nerve cell regeneration in the central nervous system, and emerging work with stem cells provide hope for the many people who are paralyzed by spinal cord injury (SCI) (**Figure 4**).

In Norrtalje, Sweden, 25-year-old Thomas Westburg sustained a serious spinal cord injury while snowmobiling. Four nerves were torn from the spinal cord in the area of the neck. The injury left Westburg's left shoulder, arm, and hand completely paralyzed. Surgeons at the Karolinska Hospital in Stockholm reattached two of the nerves. Remarkably, the repair job provided a channel along which new nerves began to grow from cell bodies in Westburg's spinal cord. The slow growth of nerve cells finally connected the spinal cord with muscles that move the arm. In Westburg's case, about 40 % of mobility was restored.

Some promising research comes from the use of stem cells. Stem cells are cells that have not yet specialized into tissue cells, such as skin, bone, muscle, or nerve cells. Scientists are experimenting with the possibility of replacing cells that have been damaged by disease or trauma, such as in cases of spinal cord injury or Parkinson's disease.

In October 2000, scientists announced that they had reconnected severed nerves in the spinal cords of rats using spore-like cells from the nervous system of adult rats. Only 3 μm (micrometres) in diameter, these repair cells are so small that some researchers first regarded them as cellular debris. The spore-like cells can be frozen for more than a month and still be retrieved for use. Properly incubated, they grow easily and can withstand a decrease in nutrients and changes of temperature. Placed in the body of a mammal, they are able to survive with limited amounts of oxygen for several days until blood vessels grow into the area. These spore-like cells can only transform into cells associated with nerve conduction.

Scientists harvested the spore-like nerve cells from the spines of healthy adult rats and seeded them into the spinal cords of injured rats. Quickly the new cells began to grow in the area of the severed cord. After 10 days, researchers recorded small twitches in the toes of the rats. Within three months, some of the rats could stand on their hind legs. The use of adult stem cells has also been proposed for this purpose. However, further research is required to determine whether these cells could be used to treat neurological diseases and injuries.

The Reflex Arc

If you accidentally touch a hot stove, you probably do not think about how your nervous system tells you that it is hot. The sensation of heat is detected by specialized temperature receptors in your skin, and a nerve impulse is carried to the spinal cord. The sensory neuron passes the impulse on to an interneuron, which, in turn, relays the impulse to a motor neuron. The motor neuron causes the muscles in the hand to contract and the hand to pull away. All this happens in less than a second, before the information even travels to the brain. Very quickly, the sensation of pain becomes noticeable and you may let out a scream.

Reflexes are involuntary and often unconscious. Imagine how badly you could burn yourself if you had to wait for the sensation of pain before removing your hand from the hot stove. The damage would be much worse if you had to go through the process of

Figure 4
Snowmobile accidents account for a high number of spinal cord injuries in Canada.

DID YOU KNOW?

Spinal Cord Injury in Canada

According to the Canadian Paraplegic Association (CPA), about 1000 new injuries a year result in some level of permanent paralysis or neurological deficit. Spinal cord injury is most common in males in the 15–34 age group.

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

Brain Band-Aid

Dr. Rutledge Ellis-Behnke (professor in the Department of Brain and Cognitive Sciences at the Massachusetts Institute of Technology) and colleagues have been working to overcome the body's natural defence systems that prevent damaged neurons from growing back and repairing. In research trials in hamsters, severed nerves have been regrown and function has been restored.

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gauging the intensity of the pain and then contemplating the appropriate action. Even the small amount of time required for nerve impulses to move through the many circuits of the brain and back to the muscle would increase the damage.

reflex arc neural circuit through the spinal cord that provides a framework for a reflex action

The simplest nerve pathway is the **reflex arc**. Most reflexes occur through a reflex arc, which do not involve coordination by the brain. Reflex arcs contain five essential components: the sensory receptor, the sensory neuron, the interneuron (most often found in the spinal cord, but in some reflex arcs, in the brain), the motor neuron, and the effector (**Figure 5**).

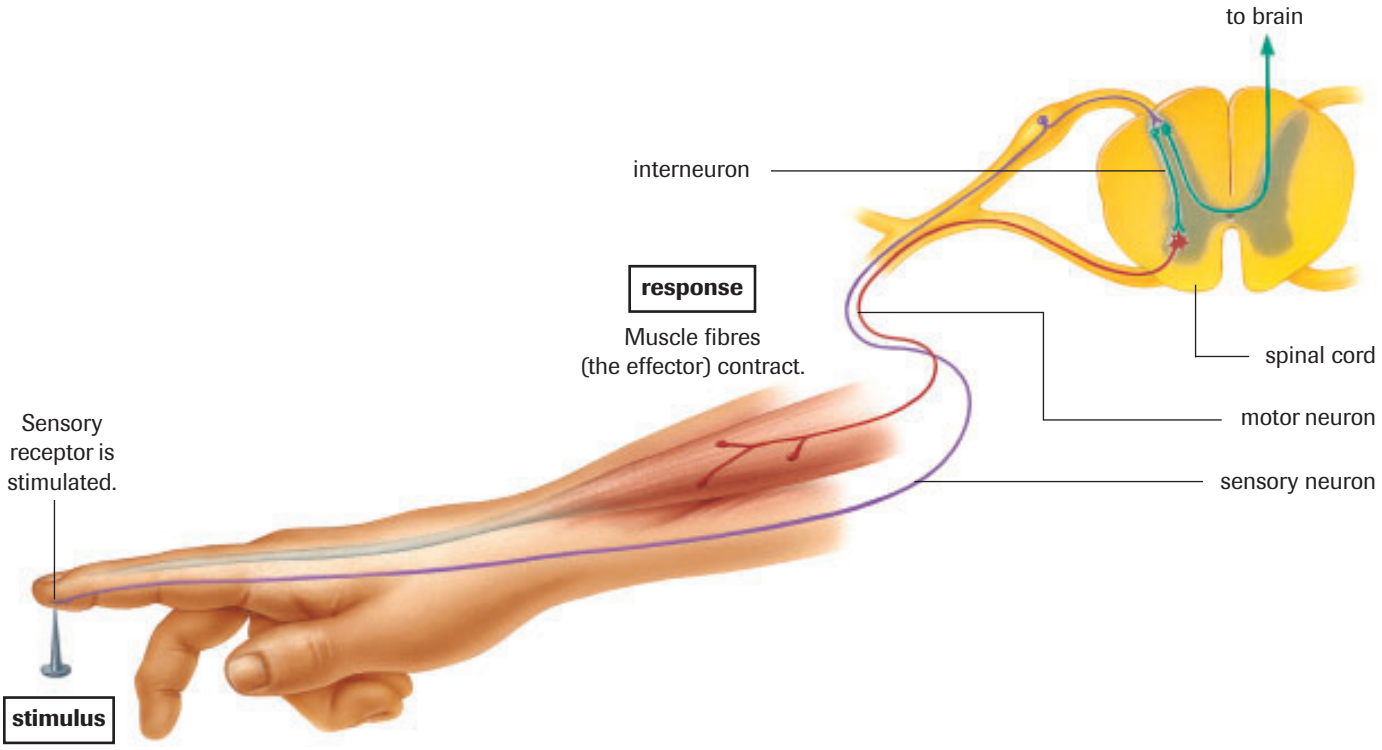

Figure 5
A reflex arc begins when the touch receptor in the finger senses the tack. Sensory information is relayed from the sensory neuron (purple) to the spinal cord. Interneurons in the spinal cord (green) receive the information from the sensory neuron and relay it to the motor neuron (red). The motor neuron activates the muscle cell (the effector), causing it to contract. The brain also receives sensory information from a sensory neuron, which registers as pain. This step is not part of the reflex arc.

Physicians may stimulate a reflex arc to test the health and functioning of parts of the nervous system. For example, the patellar reflex is stimulated by gently tapping the tendon below the kneecap. Sensory receptors detect the slight stretching of the tendon and relay an impulse to a sensory neuron (**Figure 6**, next page). The impulse travels down the sensory neuron to the spinal cord. The message has now travelled from the peripheral nervous system to the central nervous system. The central nervous system then relays a message back out to the peripheral nervous system, along two motor neurons that connect with the muscles on the upper and lower thigh (the quadriceps and hamstrings, respectively). The impulses from these motor neurons simultaneously cause the quadriceps to contract and the hamstrings to relax. As a result, the lower leg rises. This all takes place so quickly as to seem instantaneous.

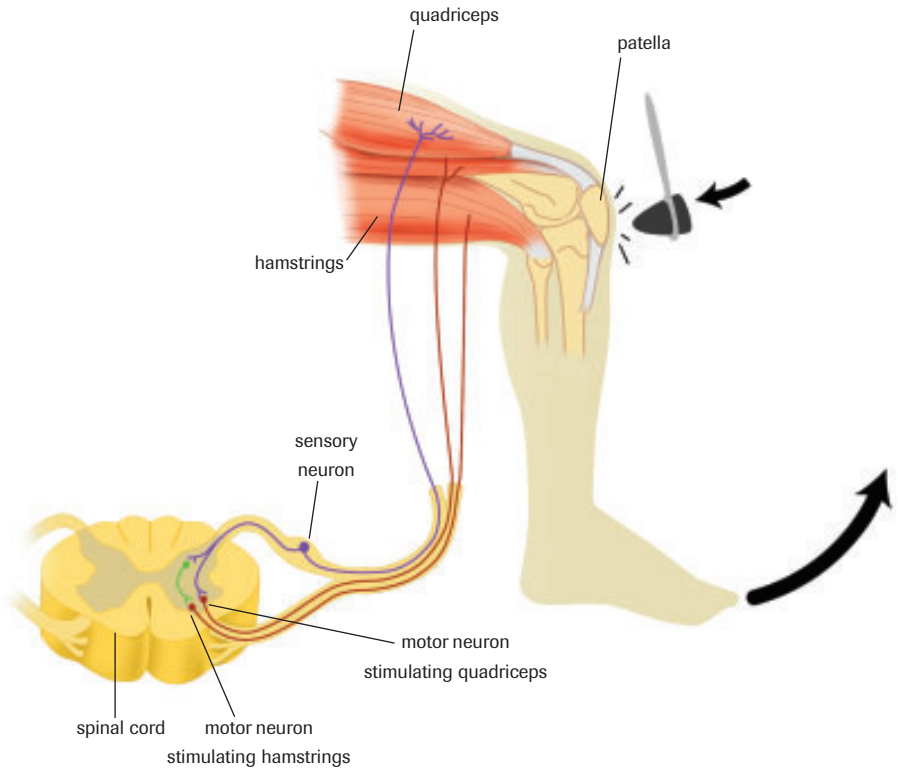

Figure 6
The patellar reflex is commonly known as the "knee-jerk response." Tapping on the ligament under the knee cap causes the lower leg to raise in response.

You may have experienced a physician quickly shining a small penlight in one eye during an examination. In this exam, the physician is looking for your pupils to constrict (become smaller) in response to the light. (This should never be done with a bright light, since it could damage the eye.) This is called the pupillary reflex. Sensors in the eye detect the light and pass an impulse to a sensory neuron. In this case, the impulse is carried to the brain. This is the point at which the message is relayed from the peripheral nervous system to the central nervous system in this reflex arc. As with the patellar reflex, the central nervous system relays a message to two motor neurons in the peripheral nervous system, one for each eye. These neurons carry an impulse to muscles in the eye that cause the pupil to contract. As a result, when a light is shone in one eye of a person with a healthy nervous system, the pupils of both eyes will respond simultaneously.

INVESTIGATION 13.1 *Introduction*

Reflex Arcs

Reflex arcs provide a framework for reflex actions. Simple physical tests can be performed to test reflexes. In this investigation, you will observe the presence and strength of a number of reflex arcs. You will also design an experiment to investigate a reflex arc.

Report Checklist

- ● Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

To perform this investigation, turn to page 436.

SUMMARY The Importance of the Nervous System

Table 1 Parts of the Nervous System

Structure	Function
neuron	• nerve cell that conducts nerve impulses
sensory neuron (afferent neuron)	• carries impulses to the central nervous system
interneuron	• carries impulses within the central nervous system
motor neuron (efferent neuron)	• carries impulses from the central nervous system to effectors
dendrite	• projection of cytoplasm that carries impulses toward the cell body
axon	• extension of cytoplasm that carries nerve impulses away from the cell body
myelin sheath	• covering over the axon of a nerve cell that is composed of Schwann cells and insulates the axon
nodes of Ranvier	• regularly occurring gaps between sections of myelin sheath that speed transmission of nerve impulses
neurilemma	• delicate membrane surrounding the axons of some nerve cells that promotes nerve regeneration
reflex arc	• neural circuit that travels through the spinal cord • provides a framework for a reflex action

Section 13.1 Questions

1. Name the essential components of a reflex arc and the function of each.
2. What would happen if neuron I in **Figure 7** was severed?
3. In **Figure 7**, what is the order in which an impulse travels along a reflex arc?
4. Primitive sporelike repair cells have been extracted from adult rats. Discuss some of the benefits of using mature repair cells.
5. The incidence of multiple sclerosis (MS) varies among different regions of Canada. Provide a possible explanation for different distributions of the disease.
6. A study on severed optic nerves showed that neurons from the peripheral nervous system grafted into the stalk of the optic nerve regrew approximately 10 % of the retinal ganglions. No reconnections were seen when severed optic-nerve neurons were left alone. What do these findings suggest?

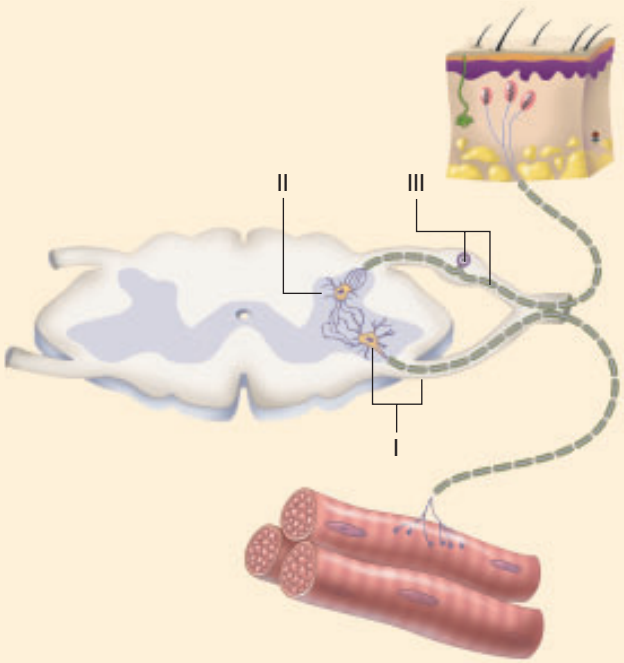

Figure 7
Reflex arc

Electrochemical Impulse 13.2

As early as 1900, German physiologist Julius Bernstein suggested that nerve impulses were an electrochemical message created by the movement of ions through the nerve cell membrane. Evidence supporting Bernstein's theory was provided in 1939 when two researchers at Columbia University, K.S. Cole and H.J. Curtis, placed a tiny electrode inside the large nerve cell of a squid (**Figure 1**). A rapid change in the electrical potential difference—commonly called the potential—across the membrane was detected every time the nerve became excited. The resting membrane normally had a potential somewhere near −70 mV (millivolts); however, when the nerve became excited, the potential on the inside of the membrane registered +40 mV. This reversal of potential is described as an **action potential**. Cole and Curtis noticed that the +40 mV did not last more than a few milliseconds (ms) before the potential on the inside of the nerve cell returned to −70 mV, the **resting potential**.

action potential the voltage difference across a nerve cell membrane when the nerve is excited

resting potential voltage difference across a nerve cell membrane when it is not transmitting a nerve impulse (usually negative)

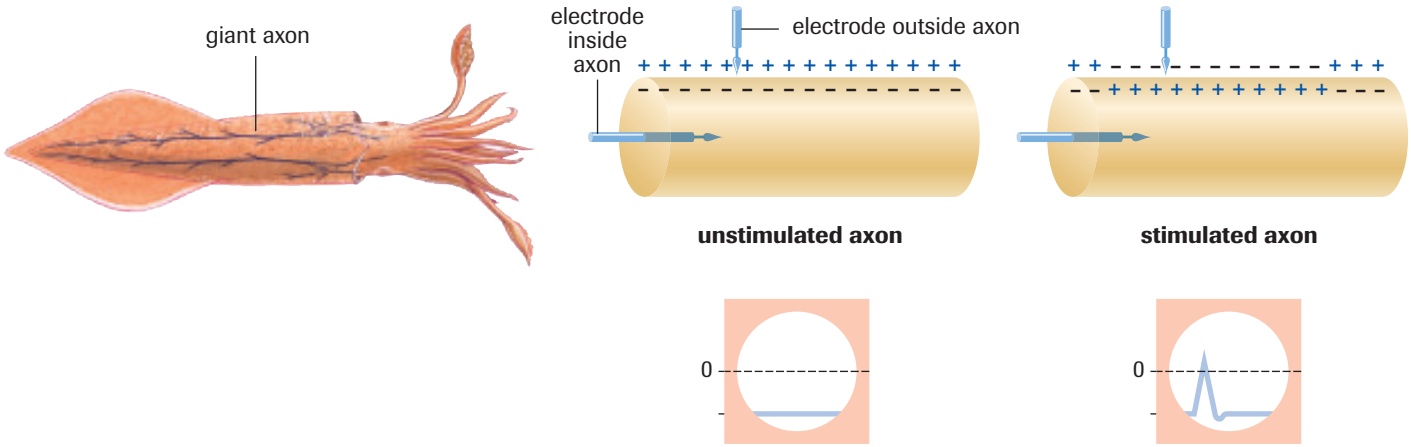

Figure 1
A miniature electrode is placed inside the giant axon of a squid. The inside of the resting membrane is negative with respect to the outside of the membrane. When stimulated, the charges across the nerve membrane temporarily reverse.

The Resting Potential

The plasma membrane of almost all cells has an electrical potential of about –70 mV. In neurons, this electrical potential is called the resting potential. What gives plasma membranes this electrical potential? If we examine the neuron on a molecular level, we can find the answer. Like almost all cells, neurons have a rich supply of positive and negative ions on both sides of the cell membrane (**Figure 2**). There is a higher concentration of potassium ions (K^+) inside the cell and a higher concentration of sodium ions (Na^+) outside the cell. The movement of K^+ is mainly responsible for creating the electrical potential.

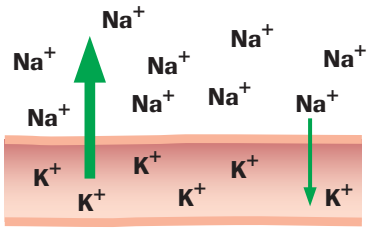

Figure 2
The K^+ concentration is higher inside the cell and the Na^+ concentration is higher outside the cell.

facilitated diffusion transport of substances across cell membrane down a concentration gradient by a carrier in the membrane; does not use energy

gated ion channel a pore in the cell membrane that allows ions to move in and out of the cell by opening and closing

sodium-potassium pump a transporter in the cell membrane that moves potassium ions into the cytoplasm while simultaneously removing sodium ions from the cytoplasm to the extracellular fluid

active transport movement of substances across cell membranes that uses energy; often moves substances against a concentration gradient

The plasma membrane of all cells, including neurons, is composed of a phospholipid bilayer. Plasma membranes are selectively permeable; ions cannot cross the bilayer by simple diffusion. Instead, they enter cells by **facilitated diffusion**, passing through **gated ion channels** that span the bilayer. Ion channels are specific to particular ions, such as K^+ or Na^+ ions.

There are many more K^+ channels than Na^+ channels in the membrane, so more K^+ diffuse out of the cell than Na^+ diffuse in (**Figure 3**). As K^+ leaves the cell, it transfers its positive charge outside the cell. The negatively charged ions are trapped inside the cell, and so an electrical charge builds up across the membrane, creating an electrical gradient. (If ion concentrations were determined only by diffusion, eventually the concentrations of sodium and potassium would equalize across the membrane. This does not happen because the **sodium-potassium pump** in the membrane moves potassium back into the cell and sodium back out of the cell through **active transport**.)

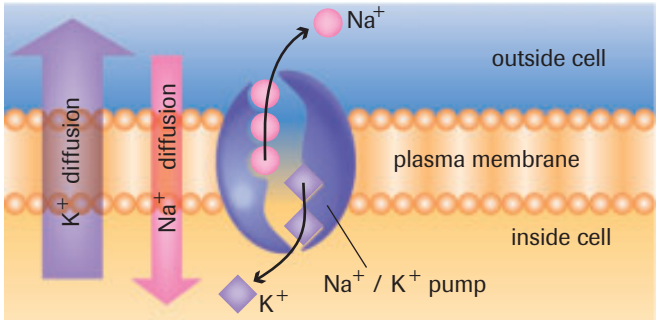

Figure 3
As potassium and sodium diffuse down their concentration gradients across the cell membrane through facilitated diffusion, the sodium-potassium pump actively transports them against the gradients.

CHEMISTRY CONNECTION

Electrolytes

An electrolyte is an aqueous electrical conductor. As in nerve cells, it is the ions in an electrolyte solution that transfer electric charge within an electric cell. Your *Chemistry 20–30* textbook will provide more information on ions and electric cells.

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Excess positive ions accumulate along the outside of the nerve membrane, while excess negative ions accumulate along the inside of the membrane. The resting membrane is said to be charged and is called a **polarized membrane**. The separation of electrical charges by a membrane has the potential to do work, which is expressed in millivolts (mV). A charge of −70 mV indicates the difference between the number of positive charges found on the inside of the nerve membrane relative to the outside. (A charge of −90 mV on the inside of the nerve membrane would indicate even fewer positive ions inside the membrane relative to the outside.)

polarized membrane membrane charged by unequal distribution of positively charged ions inside and outside the nerve cell

The Action Potential

A nerve impulse is an action potential. When a neuron receives a stimulus, the cell membrane becomes more permeable to sodium than potassium. Scientists believe that sodium channels are opened in the membrane, while potassium channels close. The highly concentrated sodium ions rush into the cell by diffusion and by charge attraction. The rapid inflow of sodium reverses the charge on both sides of the membrane.

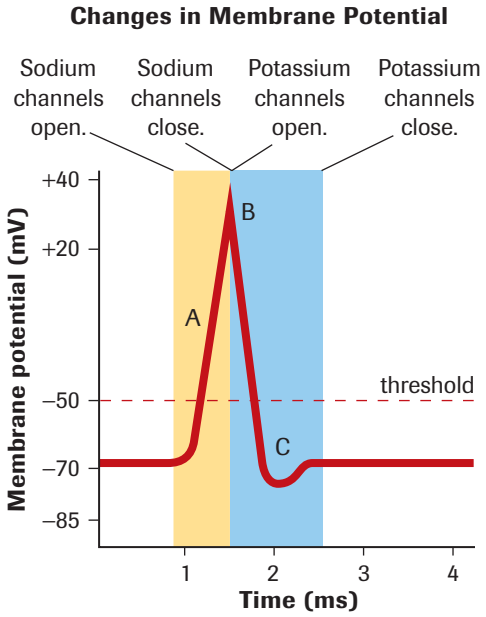

Figure 4
The phases of an action potential

This charge reversal is referred to as **depolarization** (**A** on **Figure 4**). Once the voltage inside the cell becomes positive, the sodium channels slam closed, stopping the inflow of sodium. The potassium channels then open and potassium ions diffuse out of the cell and the charge outside the cell becomes positive again. The process of restoring the original polarity of the nerve membrane is called **repolarization** (**B**). However, the potassium gates close relatively slowly and the outside of the cell becomes even more positively charged than the resting membrane (and the inside more negatively charged) as more and more potassium ions move out of the cell. This is called **hyperpolarization** (**C**). The sodium-potassium pump restores the condition of the resting membrane by transporting sodium ions out of, and potassium ions into, the cell. The time taken for the membrane to return to the resting potential after repolarization is called the **refractory period**, which lasts 1 to 10 ms. The membrane must return to the resting potential before it can generate another action potential.

Movement of the Action Potential

An action potential happens at a specific point on the nerve cell membrane. But how does it move along the cell membrane? In fact, an action potential does not move. Many action potentials are generated one after another along the cell membrane, causing a wave of depolarization. It is similar to a falling domino. When the first domino falls, it causes the domino next to it to fall, and so on.

The first action potential is generated as sodium ions rush into the cell, causing a depolarization of the membrane. The positively charged ions that rush into the nerve cell are then attracted to the adjacent negative ions, which are aligned along the inside of the nerve membrane (**Figure 5**). Similarly, the positively charged sodium ions on the outside of the resting membrane are attracted to the negative charge that has accumulated along the outside of the membrane in the area of the action potential.

depolarization diffusion of sodium ions into the nerve cell resulting in a charge reversal

repolarization process of restoring the original polarity of the nerve membrane

hyperpolarization condition in which the inside of the nerve cell membrane has a greater negative charge than the resting membrane; caused by excessive diffusion of potassium ions out of the cell

refractory period recovery time required before a neuron can produce another action potential

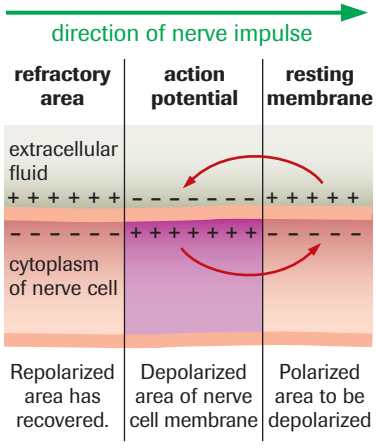

Figure 5
The movement of a nerve impulse. Red arrows indicate ions attracted to adjacent ions with opposite charges.

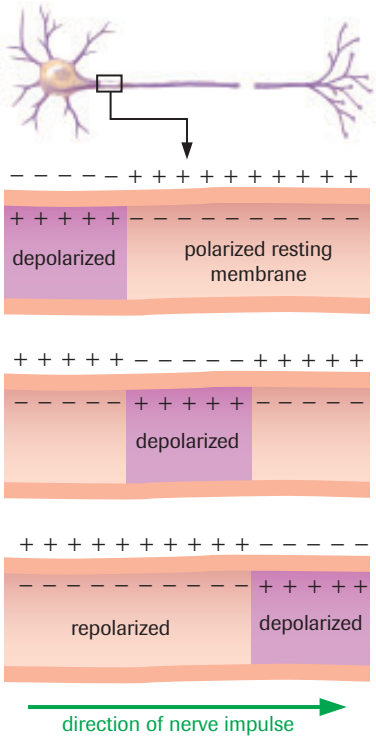

Figure 6
Successive action potentials along a section of axon cause a wave of depolarization along the cell membrane.

The flow of positively charged ions from the depolarized area toward the adjacent resting membrane causes an electrical disturbance. This electrical stimulus causes the sodium channels in the adjacent resting membrane to open, triggering an action potential next to the first action potential. The cycle keeps repeating and the action potentials cause a wave of depolarization along the membrane (**Figure 6**).

What stops the action potentials from going backwards along the cell membrane? Recall that the membrane can only produce another action potential when it is at the resting potential. Thus, during the refractory period right after an action potential, the cell membrane cannot produce another action potential because it is hyperpolarized. So, a new action potential can only be triggered at the leading edge of the first depolarized area.

When axons are myelinated, nerve impulses travel by **saltatory conduction**. In myelinated axons, the gated ion channels are concentrated at the nodes of Ranvier. The flow of ions across the cell membrane can only happen at the nodes and so action potentials have to "jump" from node to node. This causes a nerve signal to be transmitted down an axon much faster (**Figure 7**).

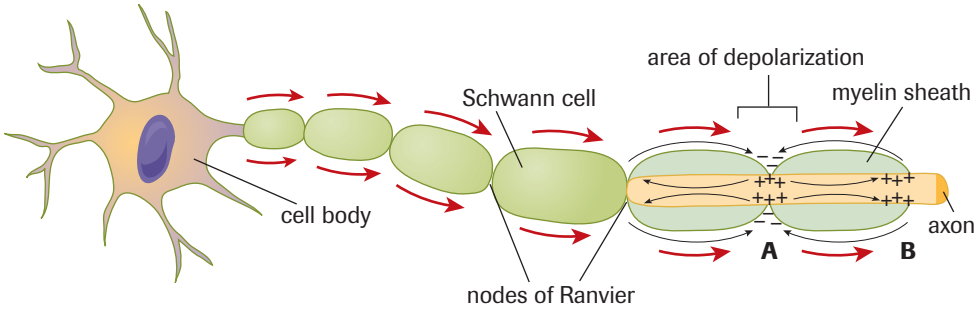

Figure 7
In myelinated axons, depolarization happens only at the nodes (**A**) and an action potential jumps to the next node (**B**). The red arrows show the direction of the nerve impulse and the black arrows show the flow of ions.

saltatory conduction generation of action potentials only at nodes of Ranvier in myelinated axons, resulting in rapid transmission of nerve impulses

Practice

1. What is a polarized membrane?
2. What causes the inside of a neuron to become negatively charged?
3. Why does the polarity of a cell membrane reverse during an action potential?
4. Why do nerve impulses move faster along myelinated nerve fibres?

Threshold Levels and the All-or-None Response

In a classic experiment, a single neuron leading to a muscle is isolated and a mild electrical shock is applied to the neuron. A special recorder measures the strength of muscle contraction. **Figure 8**, on the next page, shows sample data for this experiment. In this example, stimuli of less than 2 mV does not produce any muscle contraction. A potential stimulus must be above a critical value to produce a response. The critical intensity of the stimulus is known as the **threshold level**. Stimuli below threshold levels do not initiate a response. In **Figure 8**, although a threshold level of 2 mV is required to produce a response, threshold levels are different for each neuron.

threshold level minimum level of a stimulus required to produce a response

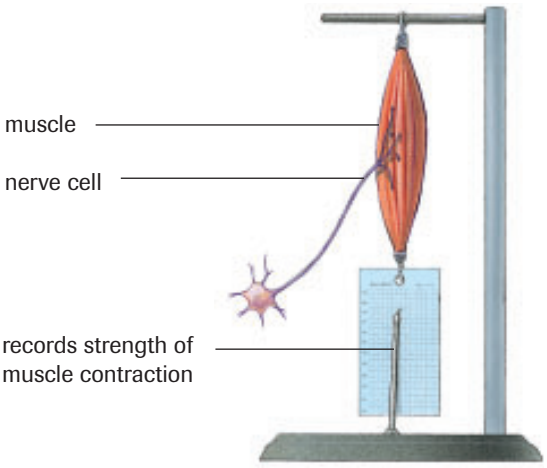

Table 1 Stimulus Strength and Force of Muscle Contraction

Strength of stimuli	Force of contraction
1 mV	–
2 mV	3 N
3 mV	3 N
10 mV	3 N

Figure 8
The threshold level for this neuron is 2 mV. Different neurons have different threshold levels.

EXTENSION

The Threshold Potential of a Neuron

Listen to this audio discussion of the reaction of a neuron to stimulus once its membrane potential has reached the threshold level.

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A second, but equally important, conclusion can be drawn from the experimental data in **Table 1**. Increasing the intensity of the stimuli above the critical threshold value will not produce an increased response—the intensity of the nerve impulse and speed of transmission remain the same. In what is referred to as the **all-or-none response**, neurons either fire maximally or not at all.

all-or-none response a nerve or muscle fibre responds completely or not at all to a stimulus

How do animals detect the intensity of stimuli if nerve fibres either fire completely or not at all? Experience tells you that you are capable of differentiating between a warm object and one that is hot. To explain the apparent anomaly, we must examine the manner in which the brain interprets nerve impulses. Although stimuli above threshold levels produce nerve impulses of identical speed and intensity, variation with respect to frequency does occur. The more intense the stimulus, the greater the frequency of impulses. Therefore, when a warm glass rod is placed on your hand, sensory impulses may be sent to the brain at a slow rate. A hot glass rod placed on the same tissue also causes the nerve to fire, but the frequency of impulses is greatly increased—a difference the brain recognizes.

The different threshold levels of neurons provide a second way for the intensity of stimuli to be detected. Each nerve is composed of many individual nerve cells or neurons. A glass rod at 40 °C may cause a single neuron to reach threshold level, but the same glass rod at 50 °C will cause two or more neurons to fire (**Figure 9**). The second neuron has a higher threshold level. The greater the number of impulses reaching the brain, the greater the intensity of the response.

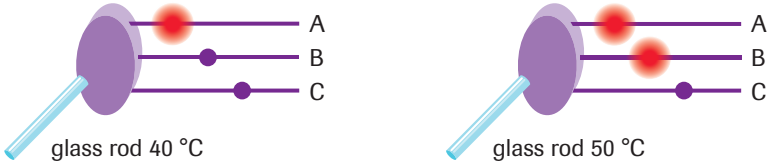

Figure 9
Neuron B has a higher threshold level than neuron A and will not fire until the glass rod is heated above 40 °C. The brain interprets both the number of neurons excited and the frequency of impulses.

Synaptic Transmission

synapse a region between neurons, or between neurons and effectors; also known as the synaptic cleft

neurotransmitter chemical messenger released by the presynaptic neuron that binds to receptors on the postsynaptic neuron

presynaptic neuron neuron that carries impulses to the synapse

postsynaptic neuron neuron that carries impulses away from the synapse

Small spaces between neurons, or between neurons and effectors, are known as **synapses**. The terminal branches of a single neuron allow it to join with many different neurons (**Figure 10**). Synapses rarely involve just two neurons. Small vesicles containing chemicals called **neurotransmitters** are located in the end plates of axons. The impulse moves along the axon and releases neurotransmitters from the end plate. The neurotransmitters are released from the **presynaptic neuron** and diffuse across the synapse, or synaptic cleft, creating a depolarization of the dendrites of the **postsynaptic neuron** when the neurotransmitters bind to receptors. Although the space between neurons is very small—approximately 20 nm (nanometres)—the nerve transmission slows across the synapse. Diffusion is a slow process. Not surprisingly, the greater the number of synapses over a specified distance, the slower the speed of transmission. This may explain why you react so quickly to a stimulus in a reflex arc, which has few synapses, while solving biology problems, which involves many more synapses, requires more time.

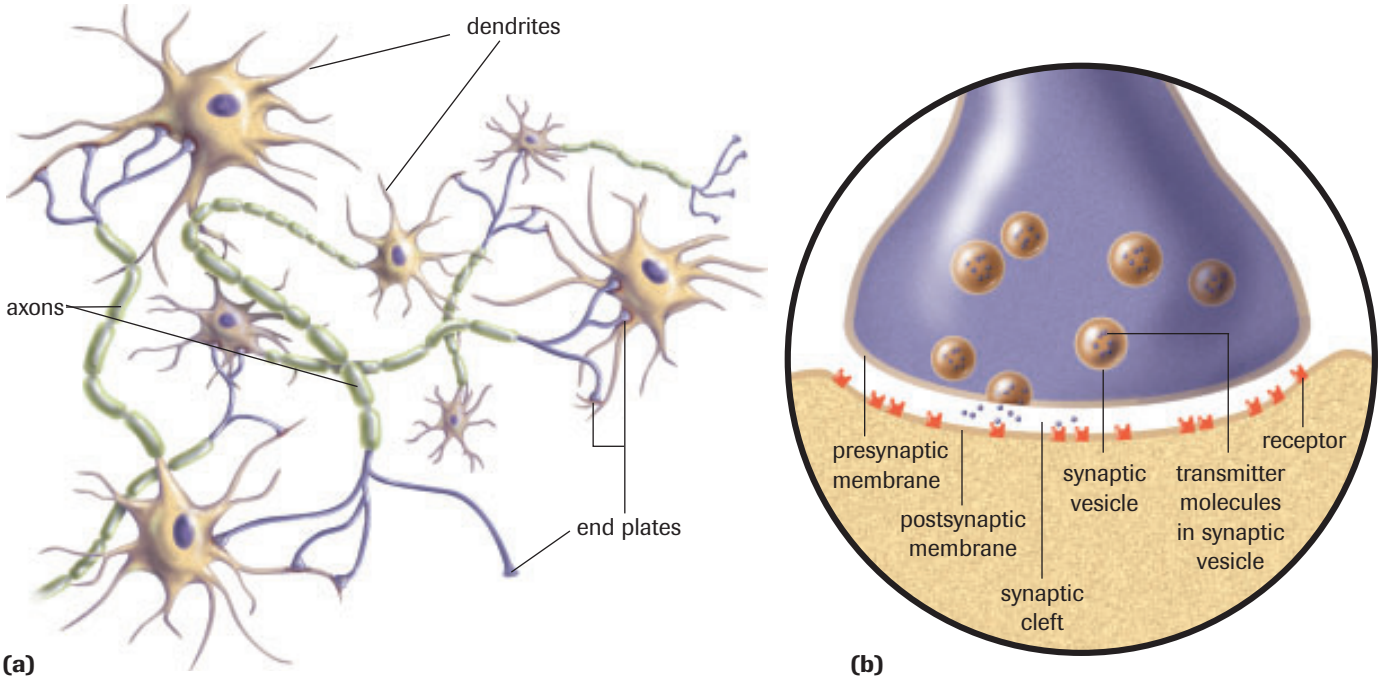

Figure 10

(a) The end plates of terminal branches synapse with the cell bodies and dendrites of many different neurons.

(b) Synaptic vesicles in the end plate of the presynaptic neuron release neurotransmitters into the synaptic cleft. The neurotransmitters attach themselves to receptors on the postsynaptic membrane, causing it to depolarize. The action potential continues along the postsynaptic neuron.

Practice

5. Some people report they have a high pain tolerance. Explain this in terms of threshold levels.

6. What is the all-or-none response?

7. Describe the path of a nerve impulse across a synapse.

mini Investigation Examining Neurons

1. Using a light microscope, examine a longitudinal view of a neuron.
   (a) Describe the appearance of the neuron.
   (b) Estimate the diameter of the neuron.
2. Follow the nerve cell to the synapse.
   (a) Describe the appearance of the synapse and draw a diagram of it.
   (b) Estimate the distance between the presynaptic neuron and the postsynaptic neuron.

EXTENSION

Calculation of Scale

Listen to this review of calculation of scale in microscopic measurements.

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3. Refer to the Nelson Web site to view different scientific models of synapses and photomicrographs of synapses taken from scanning electron microscopes and electron microscopes.

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   (a) What additional information about synapses is revealed by observing these high-magnification, high-resolution photomicrographs?
   (b) How do the scientific models help explain the functioning of the synapse?

Neurotransmitters

Neurotransmitters alter the membrane potentials of postsynaptic neurons. **Acetylcholine** is a neurotransmitter found in the end plates of many nerve cells. Acetylcholine acts as an excitatory neurotransmitter on many postsynaptic neurons by opening the sodium ion channels. Once the channels are opened, the sodium ions rush into the postsynaptic neuron, causing depolarization. The reversal of charge causes the action potential. However, the continued presence of acetylcholine also presents a problem. With the sodium channels open, the postsynaptic neuron would remain in a constant state of depolarization. How can the nerve respond to the next impulse if it never recovers? The presynaptic membrane releases the enzyme **cholinesterase**, which destroys acetylcholine. Once acetylcholine is destroyed, the sodium channels close, and the neuron begins its recovery phase. Many insecticides take advantage of the synapse by blocking cholinesterase. The heart of an insect, unlike the human heart, is totally under nerve control. An insecticide causes the insect's heart to respond to the nerve message by contracting but never relaxing.

acetylcholine neurotransmitter released from vesicles in the end plates of neurons, which makes the postsynaptic membranes more permeable to Na^+ ions

cholinesterase enzyme, which breaks down acetylcholine, that is released from presynaptic membranes in the end plates of neurons shortly after acetylcholine

Not all neurotransmitters are excitatory. For example, although acetylcholine can act as an excitatory neurotransmitter on some postsynaptic membranes, it can act as an inhibitory neurotransmitter on others. Inhibitory neurotransmitters make the postsynaptic membrane more permeable to potassium. By opening even more potassium gates, the potassium ions inside the neuron follow the concentration gradient and diffuse out of the neuron. The rush of potassium out of the cell increases the number of positive ions outside the cell relative to the number found inside the cell, and the cell membrane becomes hyperpolarized, inhibiting any action potentials. As the name suggests, these inhibitory neurotransmitters prevent postsynaptic neurons from becoming active.

DID YOU KNOW ?

Myasthenia Gravis

Drugs that temporarily keep the enzyme cholinesterase from working are used to treat myasthenia gravis, a disease of progressive fatigue and muscle weakness caused by the impaired transmission of nerve impulses.

Figure 11, on the next page, shows a model of a typical neural pathway. Neurotransmitters released from neurons A and B are both excitatory, but neither neuron is capable of causing sufficient depolarization to initiate an action potential in neuron D. However, when both neurons A and B fire at the same time, a sufficient amount of neurotransmitter is released to cause depolarization of the postsynaptic membrane. The production of an action potential in neuron D requires the sum of two excitatory neurons. This principle is referred to as **summation**.

summation effect produced by the accumulation of neurotransmitters from two or more neurons

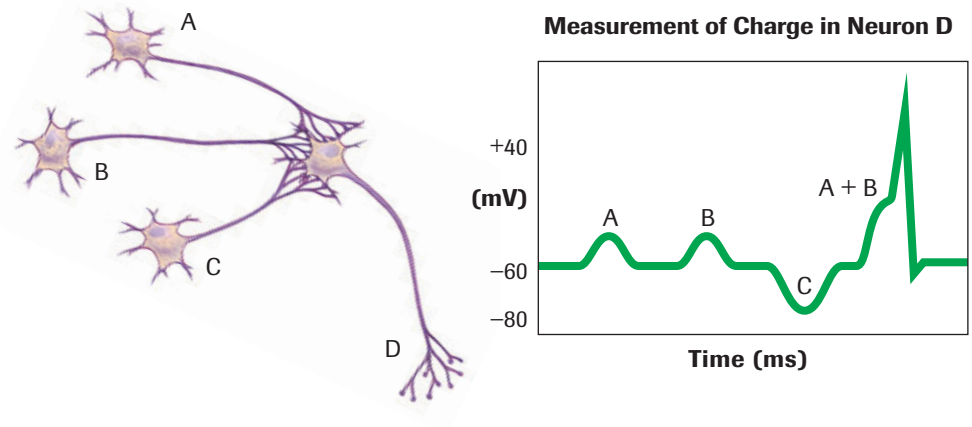

Figure 11
Action potentials must occur simultaneously in A and B to reach the threshold level in D.

The neurotransmitter released from neuron C produces a dramatically different response. Neuron D becomes more negatively charged when neuron C is activated. You may have already concluded that neuron C must release an inhibitory neurotransmitter.

The interaction of excitatory and inhibitory neurotransmitters is what allows you to throw a ball. As the triceps muscle on the back of your upper arm receives excitatory impulses and contracts, the biceps muscle on the front of your arm receives inhibitory impulses and relaxes. By coordinating excitatory and inhibitory impulses, the two muscles of the arm do not pull against each other.

Many different neurotransmitters have been identified in the nervous system. Some common ones are summarized in **Table 1**.

Table 1 Common Neurotransmitters

Neurotransmitter	Action	Secretion sites	Major effects
acetylcholine	excitatory to skeletal muscles; excitatory or inhibitory at other locations	neuromuscular functions; CNS, PNS	skeletal muscle contraction
norepinephrine	excitatory or inhibitory	CNS, PNS	wakefulness
dopamine	generally excitatory	CNS, PNS	voluntary movement and emotions
serotonin	generally inhibitory	CNS	sleep
GABA (gamma-aminobutyric acid)	inhibitory	CNS	motor behaviour

Inhibitory impulses in your central nervous system are very important. Sensory information is received by the brain and is prioritized. Much of the less important information is ignored so that you can devote your attention to the more important sensory information. For example, during a biology lecture, your sensory information should be directed at the sounds coming from your teacher, the visual images that appear on the chalkboard, and the sensations produced as you move your pen across the page. Although your temperature receptors may signal a slight chill in the air and the pressure receptors in your skin may provide the reassuring information that you are indeed wearing clothes, the information from these sensory nerves is suppressed. Inhibitory impulses help you prioritize information. That is why the inhibitory neurotransmitter GABA is the most abundant neurotransmitter in the brain.

Various disorders have been associated with neurotransmitters. Parkinson's disease, characterized by involuntary muscle contractions and tremors, is caused by inadequate production of dopamine. Alzheimer's disease, associated with the deterioration of memory and mental capacity, has been related to decreased production of acetylcholine.

CAREER CONNECTION

Mental Health Worker

Mental health workers must have an extensive knowledge about how the nervous system works. Chemical imbalances in neurotransmitters may contribute to mental health issues, such as depression and other disorders, so these health care providers must be able to identify potential problems and assess patient needs. If helping people and diagnosing problems interests you, becoming a mental health worker might be the career for you.

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Case Study

Drugs and the Synapse

Psychoactive drugs are a group of legal and illegal drugs that exert their effect on the nervous system, disrupting its ability to receive information about the external or internal environment. Because the nervous system is the primary way in which your body receives information about changes in your internal and external environment, anything that distorts the nervous system's operation will create problems.

Under normal circumstances, impulses are relayed between nerve cells in the brain by neurotransmitters. A neurotransmitter released from the presynaptic neuron attaches to receptor sites on the postsynaptic neuron. When enough receptor sites have been filled by the transmitter chemicals, the nerve cell membrane is disrupted and an impulse is initiated—the nerve cell fires. Psychoactive drugs interfere with either the movement of these transmitter molecules or their attachment to the receptor sites.

Depressants, such as tranquillizers, opiates, barbiturates, and alcohol, are a group of psychoactive drugs that slow down the action of the central nervous system. Some depressants delay the effect of transmitter chemicals by slowing the reaction of connecting nerves. Stimulants, such as cocaine, nicotine, amphetamines, and caffeine, are psychoactive drugs that speed up the action of the central nervous system. Some stimulants prevent the neurotransmitters from being broken down or recycled once they have left the receptors. The neurotransmitters remain longer than they normally would and they keep the receptor sites on the postsynaptic neuron full, resulting in more frequent firing of the neuron.

Different drugs act at different points in the normal sequence of events to affect neurotransmission. They may have stimulant or depressant effects by any of the mechanisms listed below.

Effects of a Stimulant on Neurotransmission

(a) A drug mimics the neurotransmitter and stimulates the receptor at the receptor site ((**2**) in **Figure 12**).
(b) A drug decreases the rate of breakdown or diffusion of the neurotransmitter from the receptor site.
(c) A drug increases the rate of release of the neurotransmitter from storage at the presynaptic neuron (**1**).

Effects of a Depressant on Neurotransmission

(a) A drug blocks the receptor site and so the normal neurotransmitter cannot interact with the receptor (**2**) and send an impulse.
(b) A drug decreases synthesis and storage of the neurotransmitter at the presynaptic neuron (**5**).
(c) A drug increases the rate of breakdown of the neurotransmitter on the postsynaptic membrane (**3**) or in the synaptic cleft (**4**).

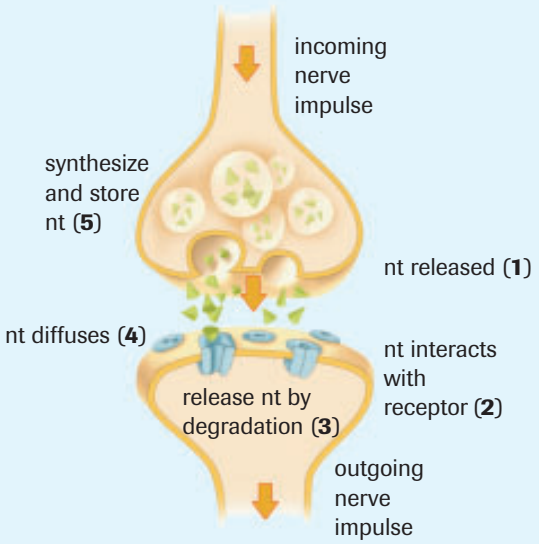

Figure 12
The path of neurotransmitters (nt) in the synapse

Opiates

In the 1970s, scientists discovered that the brain had receptors for opiates such as codeine, morphine, and heroin. These receptors were located in parts of the brain important for breathing, pain, and emotions. Scientists wondered why the brain had these receptors. Later it was discovered that opiates have a similar chemical structure to endorphins, naturally occurring painkillers that the brain manufactures. Endorphins are always in the brain, but they are released in greater amounts when a person is in pain or under stress. Pain is interpreted by specialized cells in the dorsal part of the spinal cord. When stimulated, these cells produce a neurotransmitter that "informs" the injured area of the damage. Increasing the amount of the pain neurostransmitter released increases the perception of pain. Endorphins block the production of pain neurotransmitters and so can block feelings of pain or stress. When people take opiates, the main effect is relief from pain.

In addition to pain relief, opiates cause other effects: euphoria, drowsiness, and reduced anxiety. Not all of the mechanisms by which opiates produce these effects are known. It is generally believed that opiates stimulate the reward pathway in the brain (**Figure 13**, next page). The reward pathway is designed to reinforce behaviours that are essential to survival, such as drinking when thirsty. Stimulating neurons in these pathways brings on pleasant, happy feelings that encourage repetition of the behaviour that led to the stimulation of the pathway. The neurons in the reward pathway use the neurotransmitter dopamine. One theory is that stimulating opiate receptors inhibits the release of the neurotransmitter GABA, which normally inhibits the release of dopamine, so dopamine release is increased in the reward pathway.

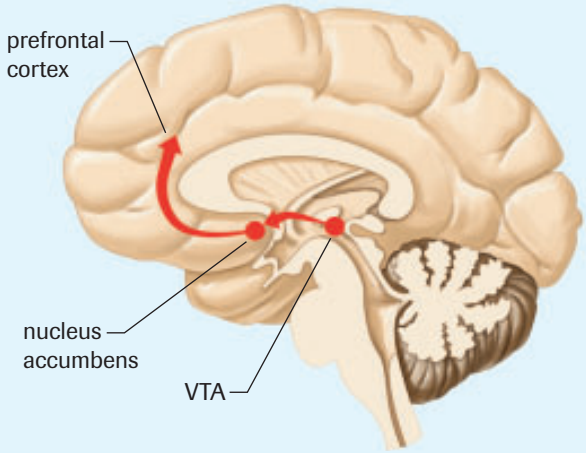

Figure 13
The reward pathway involves three different parts of the brain: the ventral tegmental area (VTA), nucleus accumbens, and the prefrontal cortex.

Alcohol

Alcohol, a depressant, is one of the most widely used and abused of the psychoactive drugs. It affects the central nervous system in many different ways. It enhances the effects of the neurotransmitter GABA, which is an inhibitory transmitter. It also weakens the effect of the neurotransmitter glutamine, which is an excitatory transmitter. Weakening an excitatory transmitter has the same effect as enhancing an inhibitory transmitter: both make a person sluggish. Alcohol does this by interacting with receptors for these neurotransmitters on the postsynaptic membrane. Alcohol also increases the production of endorphins.

Alcohol affects different areas of the brain. In the cerebral cortex, alcohol depresses behavioural inhibitory centres, slows down the processing of information from the senses, and inhibits thought processes. Alcohol affects the hippocampus, causing exaggerated emotions. By acting on the cerebellum, which controls fine motor movement, alcohol inhibits coordination.

Nicotine

Nicotine is one of the most widely used, and most addictive, stimulants. A component of the tobacco plant, it is commonly taken in with cigarette smoke. When inhaled, nicotine reaches the brain in approximately 10 seconds. Nicotine mimics acetylcholine and binds to acetylcholine receptors. This leads to an increase in energy level, heart rate, and breathing rate. When nicotine binds to certain receptor sites, it stimulates the production of endorphins, which promotes the release of the neurotransmitter dopamine in the reward pathway.

Cocaine

Made from a plant called *Erythroxylon coca*, cocaine is a stimulant. It can be taken by chewing on coca leaves, smoked, inhaled ("snorted"), or injected. When cocaine reaches the brain, it causes feelings of euphoria, excitement, reduced hunger, and strength. It also increases heart rate and blood pressure. Cocaine prevents the reuptake of norepinephrine, seratonin, and dopamine, so these remain in the synaptic cleft for a longer time.

Cocaine stimulates neurons in the reward pathway, among other areas of the brain. By stimulating the reward pathway, the user has a feeling of well-being, which reinforces use of the drug.

Addiction

Prolonged use of all these drugs can lead to **addiction**. Addiction is a behavioural phenomenon: a person who is addicted loses self-control. Addicts focus their attention on the drug over all other things, even when they are harming themselves. Addiction also involves two other physical phenomena: physical dependence and tolerance. Physical dependence means that if a person suddenly stops taking the drug, she or he goes through withdrawal. Tolerance means that, over time, a person needs an increased amount of the drug in order to produce the desired effect.

Case Study Questions

1. (a) Provide a diagram that shows how a psychoactive drug interferes with receptor sites on the postsynaptic neuron.
   (b) Why are such diagrams, known as scientific models, useful?
2. Alcohol also decreases the production of acetylcholine. Link decreased production of acetylcholine production to decreased reaction times.
3. Describe the behaviour of a person who has had too much to drink and relate each symptom to events in the central nervous system.
4. Why might someone take opiates?
5. Draw a diagram that shows how an opiate affects the synapse.
6. What is the result of having increased levels of dopamine in the synapses of the reward pathway?
7. During the mid-1990s, the death of two elite basketball players was linked to the use of cocaine. Explain why using a stimulant prior to exercise is dangerous.
8. How might an understanding of the effects of depressants and stimulants affect a person's decisions about whether to take these kinds of drugs?
9. Amphetamines are drugs that are often abused. Find out how amphetamines affect the synapse and the effects they have on the brain.

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SUMMARY Electrochemical Impulse

- Nerves conduct electrochemical impulses from the dendrites along the axon to the end plates of the neuron.
- Active transport and diffusion of sodium and potassium ions establish a polarized membrane.
- An action potential is caused by the inflow of sodium ions.
- Nerve cells exhibit an all-or-none response.
- Neurotransmitters allow the nerve message to move across synapses.

EXTENSION

In Pursuit of Ecstasy

This brief video shows how the recreational drug ecstasy affects neurotransmitters in the brain, and how these changes can have serious side-effects, including permanent changes in brain chemistry and, in a few cases, death.

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Section 13.2 Questions

1. Why was the squid axon particularly appropriate for nerve research?
2. What changes take place along a nerve cell membrane as it moves from a resting potential to an action potential to a refractory period?
3. In **Figure 14**, which area(s) of the graph indicate(s) the opening of Na^+ ion channels and the diffusion of Na^+ ions into the nerve cells? Explain your answer.

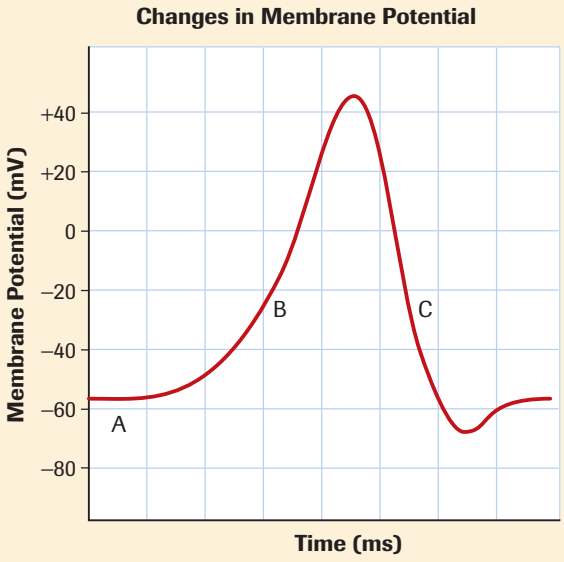

Figure 14
Action potential

4. In **Figure 14**, repolarization occurs in which areas? Explain your answer.
5. Use the synapse model in **Figure 15** to explain why nerve impulses move from neuron A to neuron B, but not from neuron B back to neuron A.

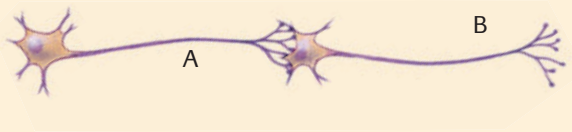

Figure 15
Nerve pathway

6. Explain the functions of acetylcholine and cholinesterase in the transmission of nerve impulses.
7. The action of many psychoactive drugs can be explained in terms of neurotransmitters. Valium, a depressant, interacts with gamma-amino-butyric acid (GABA) transmitter–receptor sites on postsynaptic membranes. The greater the number of receptor sites that are occupied, the more effective the neurotransmitter. LSD and mescaline, both hallucinogenic drugs, are thought to interact with the receptor sites of serotonin.
   (a) Draw a diagram that shows how Valium and hallucinogenic drugs work.
   (b) What dangers exist from taking drugs that interfere with naturally produced neurotransmitter chemicals?
8. The neurotransmitter serotonin is normally involved in temperature regulation, sensory perception, and mood control. A class of compounds known as selective serotonin reuptake inhibitors (SSRIs) has proven highly successful in the treatment of depression, anxiety, and obsessive-compulsive disorder (OCD). (The drug Prozac is a commonly prescribed SSRI.) How do these therapeutic drugs affect serotonin? Are there any risks involved? Search for information in newspapers, periodicals, CD-ROMs, and on the Internet.

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13.3 The Central Nervous System

The central nervous system consists of the brain and spinal cord. The brain is formed from a concentration of nerve tissue in the anterior portion of animals and acts as the coordinating centre of the nervous system. Enclosed within the skull, the brain is surrounded by a tough three-layer protective membrane known as the **meninges**. The outer membrane is called the *dura mater*, the middle layer is the *arachnoid mater*, and the inner layer is the *pia mater*. These three membrane layers protect the brain.

meninges protective membranes that surround the brain and spinal cord

Cerebrospinal fluid circulates between the innermost and middle meninges of the brain and through the central canal of the spinal cord. The cerebrospinal fluid acts both as a shock absorber and a transport medium, carrying nutrients to brain cells while relaying wastes from the cells to the blood. Physicians can extract cerebrospinal fluid from the spinal cord to diagnose bacterial or viral infection. The technique, referred to as a lumbar puncture or spinal tap, is used to identify poliomyelitis and meningitis.

cerebrospinal fluid cushioning fluid that circulates between the innermost and middle membranes of the brain and spinal cord; it provides a connection between neural and endocrine systems

The Spinal Cord

The spinal cord carries sensory nerve messages from receptors to the brain and relays motor nerve messages from the brain to muscles, organs, and glands. Emerging from the skull through an opening called the foramen magnum, the spinal cord extends downward through a canal within the backbone (**Figure 1**). A cross section of the spinal cord reveals the two types of nerve tissue introduced earlier in this chapter: white matter and grey matter. Although the central grey matter consists of nonmyelinated interneurons, the surrounding white matter is composed of myelinated nerve fibres from the sensory and motor neurons. The interneurons are organized into nerve tracts that connect the spinal cord with the brain. A dorsal root brings sensory information into the spinal cord, while a ventral root carries motor information from the spinal cord to the peripheral muscles, organs, and glands (effectors).

DID YOU KNOW ?

Meningitis

Meningitis is caused by a bacterial or viral infection of the outer membranes of the brain. Its symptoms include fever, vomiting, an intense headache, and a stiff neck. If left untreated, bacterial meningitis can lead to death.

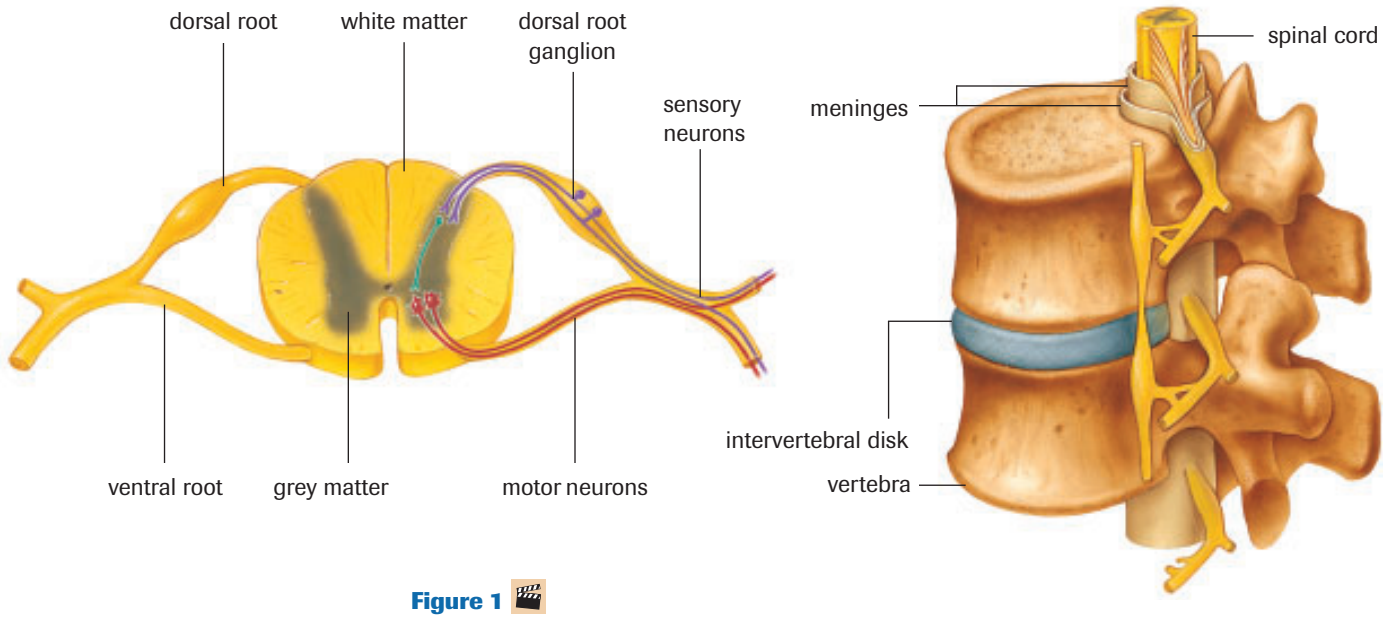

Figure 1
The spinal cord is protected by the vertebral column. Sensory nerves enter the spinal cord through the dorsal root, and motor nerves leave through the ventral root.

WEB Activity

Web Quest—Spinal Cord Research

Spinal cord injuries can be devastating, although most individuals go on to live very complete and active lives. Thanks to advances in spinal cord research, people living with these injuries have more technology and research than ever to support them. This Web Quest takes you deep into the world of spinal cord injury research. You will be required to come up with a persuasive argument for increased funding in one of several remarkable directions, including healing damaged spinal columns, re-growing new cells and even changing the way the body uses the spinal cord.

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Brain Structure and Function

What makes *Homo sapiens* unique is intellect and the reasoning functions of the brain. However, despite its apparent uniqueness, the human brain has developmental links with other chordates (**Figure 2**). As in primitive vertebrates, the human brain comprises three distinct regions: the forebrain, the midbrain, and the hindbrain.

Figure 2
The greatest evolutionary changes in the human brain have occurred in the forebrain. Coloured in blue, the forebrain is the site of reason, intellect, memory, language, and personality.

In humans, the forebrain is greatly enlarged and is comprised of many regions. The **cerebrum** forms the largest part of the forebrain and is divided into left and right hemispheres. These two giant hemispheres act as the major coordinating centre from which sensory information and accompanying motor actions originate. Speech, reasoning, memory, and even personality reside within these paired cerebral hemispheres. The surface of the cerebrum is known as the **cerebral cortex**. Composed of grey matter, the cortex has many folds that increase surface area. The deep folds are known as fissures.

cerebrum largest and most highly developed part of the human brain, which stores sensory information and initiates voluntary motor activities

cerebral cortex outer layer of the cerebral hemispheres

Each hemisphere can be further subdivided into four lobes (**Figure 3**, next page): the frontal lobe, the temporal lobe, the occipital lobe, and the parietal lobe. **Table 1**, on the next page, lists the functions of each of the lobes.

Stimulation of the motor cortex by electrical probes can trigger muscles in various parts of the body. Not surprisingly, the number of nerve tracts leading to the thumb and fingers is greater than the number leading to the arms or legs, since the thumb and fingers are capable of many delicate motor movements. Wrist and arm movements, by contrast, are limited and, therefore, regulated by fewer nerves. **Figure 4**, on the next page, shows parts of the human body drawn in proportion to the number of motor nerves that control them. Note the size of the tongue and mouth. Human speech depends on subtle changes in the position of the tongue and mouth.

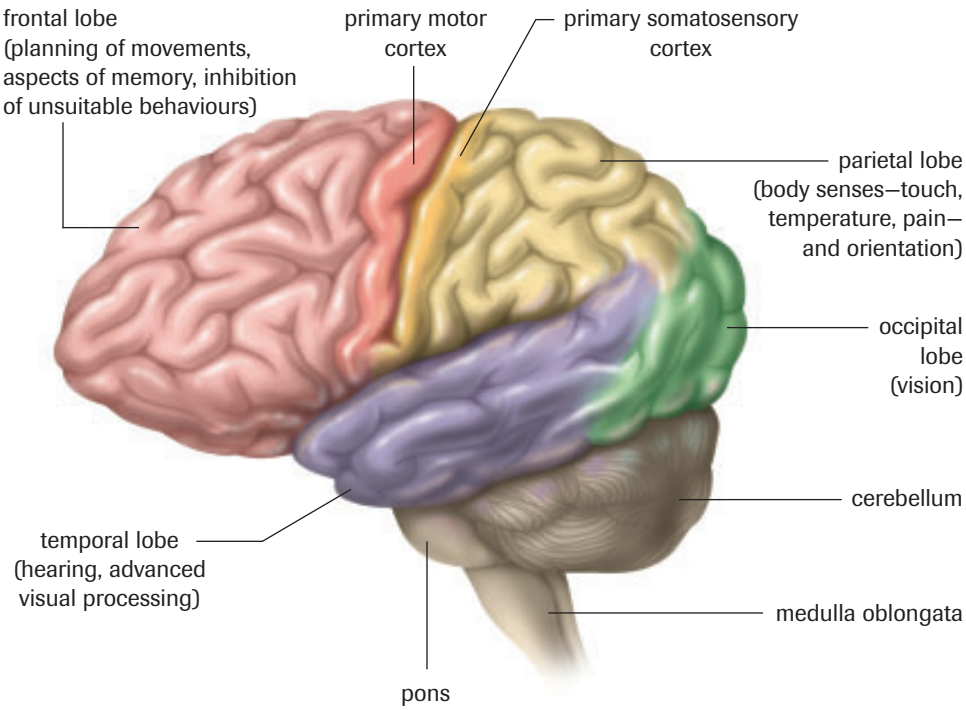

Figure 3
Primary receiving and integrating centres of the human cerebral cortex. Primary cortical areas receive signals from receptors on the body's periphery. Association areas coordinate and process sensory input from different receptors.

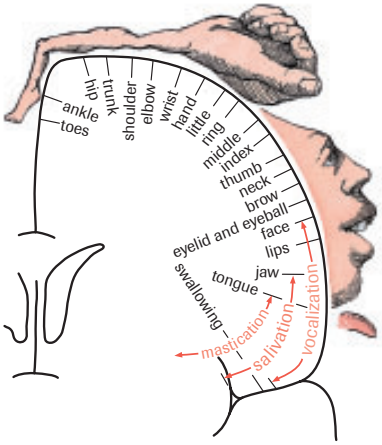

Figure 4
Regions of the body are drawn in proportion to the area of the motor cortex required to control the region.

Table 1 The Lobes of the Cerebrum

Lobe	Function
frontal lobe	• Motor areas control movement of voluntary muscles (e.g., walking and speech). • Association areas are linked to intellectual activities and personality.
temporal lobe	• Sensory areas are associated with vision and hearing. • Association areas are linked to memory and interpretation of sensory information.
parietal lobe	• Sensory areas are associated with touch and temperature awareness. • Association areas have been linked to emotions and interpreting speech.
occipital lobe	• Sensory areas are associated with vision. • Association areas interpret visual information.

corpus callosum nerve tract that joins the two cerebral hemispheres

thalamus area of brain that coordinates and interprets sensory information and directs it to the cerebrum

hypothalamus area of the brain that coordinates many nerve and hormone functions

Research has demonstrated that information stored in one side of the brain is not necessarily present in the other. The right side of the brain has been associated with visual patterns or spatial awareness; the left side of the brain is linked to verbal skills. Your ability to learn may be related to the dominance of one of the hemispheres. A bundle of nerves called the **corpus callosum** (**Figure 5**, next page) allows communication between the two hemispheres.

The thalamus, hypothalamus, and olfactory bulbs are also part of the forebrain. The **thalamus** acts as a relay station, directing incoming sensory information to the appropriate parts of the cerebrum for interpretation. The **hypothalamus** is a small part of the brain but it plays a large role in maintaining the body's internal equilibrium. A direct connection between the hypothalamus and the pituitary gland unites the nervous system with the endocrine system. (The role of the hypothalamus and the endocrine system

will be discussed in greater detail in chapter 15.) Located on the bottom of the temporal lobes, the **olfactory bulbs** receive and interpret information about smell.

olfactory bulb area of the brain that processes information about smell; one bulb in each hemisphere

The midbrain lies just below the thalamus. Consisting of four spheres of grey matter, the midbrain acts as a relay centre for some eye and ear reflexes. The hindbrain, as the name suggests, is found posterior to the midbrain and joins with the spinal cord. The cerebellum, pons, and medulla oblongata are the major regions of the hindbrain. The **cerebellum**, located immediately beneath the two cerebral hemispheres, is the largest section of the hindbrain. The cerebellum controls limb movements, balance, and muscle tone. Have you ever considered the number of coordinated muscle actions required to pick up a pencil? The hand must be opened before it touches the pencil; the synchronous movement of thumb and fingers requires coordination of both excitatory and inhibitory nerve impulses.

cerebellum part of the hindbrain that controls limb movements, balance, and muscle tone

The **pons**, meaning "bridge," is largely a relay station that passes information between the two regions of the cerebellum and between the cerebellum and the medulla. The posterior region of the hindbrain is the **medulla oblongata**. Nerve tracts from the spinal cord and higher brain centres run through the medulla, which acts as the connection between the peripheral and central nervous systems. The medulla oblongata controls involuntary muscle action. Breathing movements, the diameter of the blood vessels, and heart rate are but a few things regulated by this area of the hindbrain. The medulla oblongata also acts as the coordinating centre for the autonomic nervous system.

pons region of the brain that acts as a relay station by sending nerve messages between the cerebellum and the medulla

medulla oblongata region of the hindbrain that joins the spinal cord to the cerebellum; one of the most important sites of autonomic nerve control

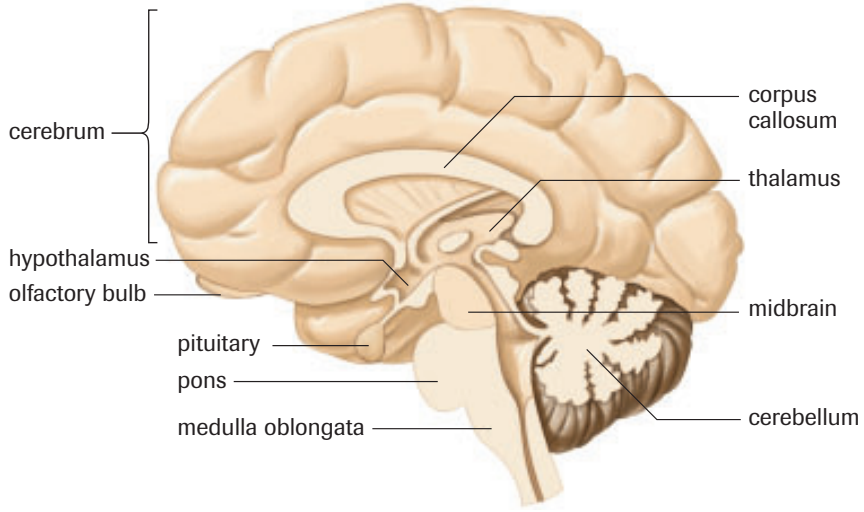

Figure 5
The human brain cut lengthwise between the two cerebral hemispheres

Practice

1. List the parts of the forebrain.
2. List the parts of the hindbrain.
3. What is the structure that connects the two cerebral hemispheres?
4. What is the function of the pons?

INVESTIGATION 13.2 *Introduction*

Brain Dissection

In this investigation you will perform a dissection of a sheep's brain to identify principal brain structures and relate them to human brain structures.

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	● Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	● Evidence	

To perform this investigation, turn to page 437.

Figure 6
In the 1940s and early 1950s, Dr. Wilder G. Penfield studied brain structure and function in living humans using a surgical procedure.

WEB Activity

Canadian Achievers—Dr. Wilder G. Penfield

Dr. Wilder G. Penfield (1891–1976), founder of the Montreal Neurological Institute, was the foremost pioneer in brain mapping. Using electrical probes, Penfield (**Figure 6**) located three speech areas within the cerebral cortex. Interestingly, the predominant speech areas reside on the left side of the brain. Penfield's finding dismissed the once-held notion that the two hemispheres were mirror images of each other. Penfield also spent a great deal of his time mapping the cerebral cortex of people with epilepsy. Penfield developed a surgical technique that involved removing a section of the skull and probing the brain with electrodes to locate the diseased area. Find out more about Dr. Penfield and how his research improved understanding and treatment of this brain disorder.

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Case Study

Phineas Gage

In September 1848, a thunderous explosion shook the ground near the small town of Cavendish, Vermont. Phineas Gage, the 25-year-old foreman of a railway construction crew, lay on the ground impaled by a tamping iron. Apparently Gage had accidentally set off blasting caps by tamping them with a large iron bar. A closer examination revealed that the metre-long bar had entered his skull immediately below the left eye and exited through the top of the skull (**Figure 7**). Incredible as it may seem, Phineas Gage recovered from the explosion and lived for another 12 years. He showed no signs of physical impairment. His vision, hearing, balance, and speech remained intact. However, he did experience one change: the once quiet and thoughtful Phineas became irresponsible and short-tempered. Spontaneous temper tantrums would send him into a fit of profanity. What could have triggered such changes?

Case Study Questions

1. Which lobe of Gage's brain was damaged?
2. Provide a hypothesis to explain why Phineas Gage's personality changed. How would you test your hypothesis?
3. In 1949, Portuguese neurologist Antonio Egas Moniz received the Nobel Prize for his surgical procedure—known as prefrontal leukotomy—in which some of the nerve tract between the thalamus and the frontal lobes is severed. Why might a physician attempt such an operation?

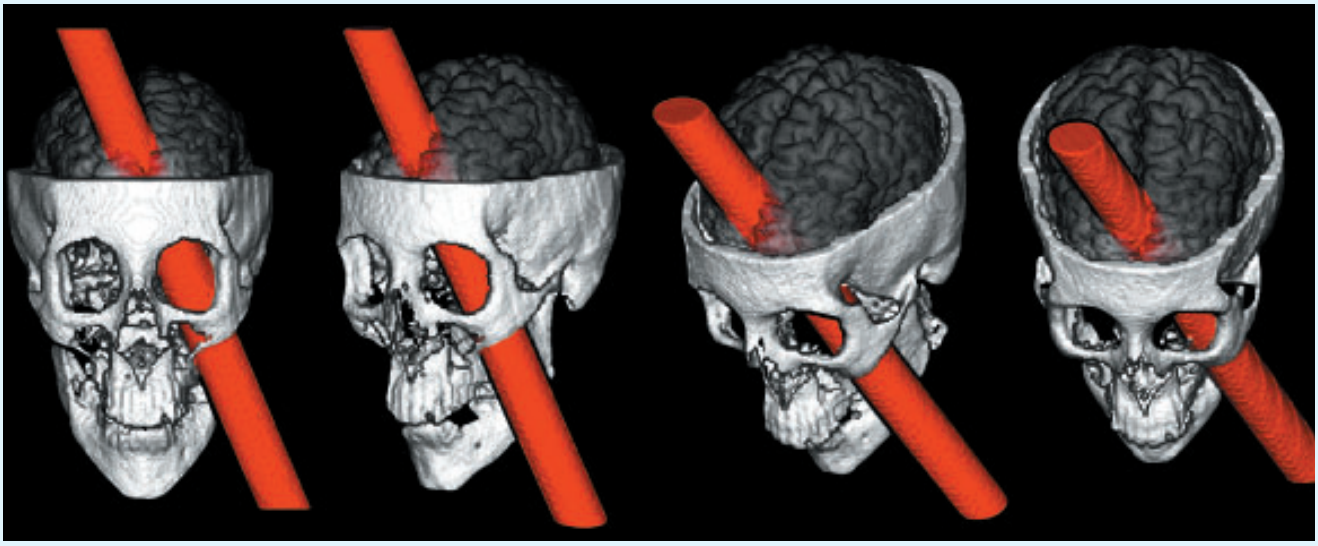

Figure 7
Computer model of the skull of Phineas Gage shown from four angles

WEB Activity

Case Study—Neuroimaging

Non-invasive imaging techniques are now available to researchers studying normal body functions and to physicians diagnosing various disorders, including cancer. These techniques are especially useful in neuroimaging—viewing the brain. Visit the Nelson Web site to learn more about positron-emission tomography (PET scans) and magnetic resonance imaging (MRI) (**Figure 8**) and other techniques. How do these techniques work and what can they reveal about the brain?

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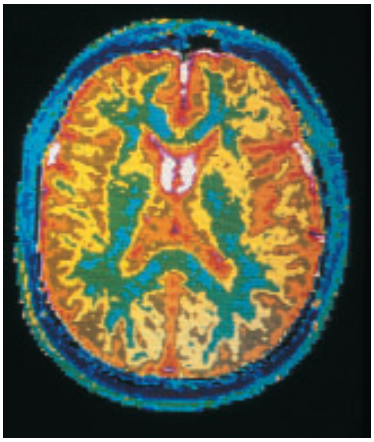

Figure 8
MRI image of a normal human brain

Research into Treatments for Alzheimer's Disease

Alzheimer's disease is a progressive, degenerative neurological disease often linked with aging. The most common symptoms are deterioration of thinking and of memory. Although it is more common in people over 65 years of age, it can affect people in their 40s. The cause of Alzheimer's disease is unknown. While family history puts individuals at a slightly higher risk, there is no clear genetic cause. Scientists currently believe that environmental factors, such as water or air pollution, may play a greater role in the development of the disease. In 2005, an estimated 280 000 Canadians over the age of 65 had Alzheimer's disease. By the year 2031, experts predict that the number will rise to 509 000.

One of the characteristics of brain tissue of Alzheimer's patients is the production of plaques and tangles (**Figure 9**). Plaques are created when a normal process goes awry. Healthy brains have microscopic deposits that contain a protein called beta amyloid. The beta amyloid has been split off from a larger protein by enzymes called secretases. In the brain of an Alzheimer's patient, secretases appear to work too well and produce too much beta amyloid. The large amounts of beta amyloid are deposited as amyloid plaques, which destroy neurons. Tangles form when healthy neurons begin to grow and behave abnormally. These tangles eventually choke and kill the neuron. As more neurons die, the patient loses brain tissue.

Knowing the biological basis of the disease gives researchers ideas about how to treat it. One of the most ambitious research efforts has been directed toward finding a vaccine to prevent the disease. By injecting antibodies against beta amyloids, researchers hope to reduce abnormal levels in Alzheimer's patients.

EXTENSION

Profile: Erich Jarvis

The work of neuroscientist Erich Jarvis demonstrates the power of open-mindedness in the lab. Find out why he chose a career in science over dance, why he calls himself a scientific artist, and why he finds bird brains so interesting by viewing this *NOVA* video.

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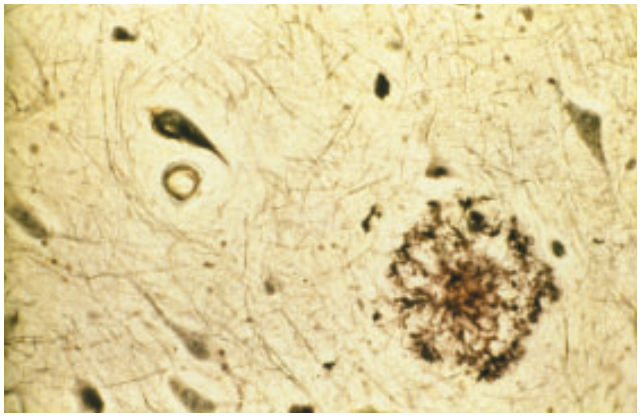

Figure 9
The large dark patch, lower right, is a beta amyloid plaque. The dark triangle, upper left, is a neuron filled with tangles.

EXTENSION

Secrets of the Mind: Probe the Brain

Canadian brain surgeon Wilder Penfield mapped the brain's motor cortex by applying mild electric currents to the exposed brains of patients.

In this *NOVA* simulation, you will apply a virtual electric probe to an exposed brain. You will apply small shocks and observe how the body responds.

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SUMMARY The Central Nervous System

Table 2 Function of the Main Structures of the Central Nervous System

Structure	Function
meninges	• protective membranes that surround the brain and spinal cord
cerebrospinal fluid	• circulates between the innermost and middle membranes of the brain and spinal cord • acts as a transport medium and shock absorber (cushion)
cerebrum	• the largest and most highly developed part of the human brain • stores sensory information and initiates voluntary motor activities
cerebral cortex	• the outer layer of the cerebral hemispheres
corpus callosum	• a nerve tract that allows communication between the two cerebral hemispheres
cerebellum	• the region of the brain that coordinates muscle movement
hypothalamus	• maintains the body's internal equilibrium
pons	• the region of the brain that acts as a relay station by sending nerve messages between the cerebellum and the medulla
medulla oblongata	• the hindbrain region that joins the spinal cord to the cerebellum • the site of autonomic nerve control

Section 13.3 Questions

1. List the four regions of the cerebral cortex and state the function of each.
2. Name the different areas of the brain labelled on **Figure 10** and indicate the functions of the different areas.

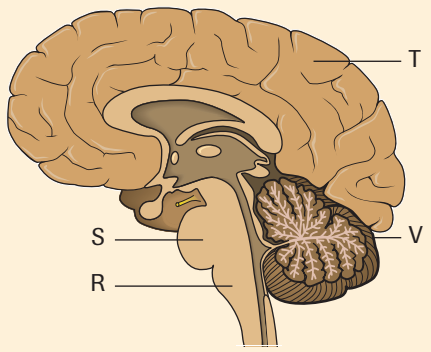

Figure 10
Human brain

3. A physician makes an incision completely through the corpus callosum. How might this affect the patient?
4. Compare the evolutionary development of the human brain to that of a fish's brain. What special advancements are noted in the human brain?
5. The old saying that "an elephant never forgets" seems to have some basis. What area of the brain would you examine to begin researching this question? Explain why.
6. Studies have been conducted to attempt to demonstrate the mental or reasoning superiority of some people based on skull size. Critique these studies.
7. Conduct an information search on strokes, including the causes, risk factors, warning signs, and effects on the various body systems. Include statistics on the incidence of strokes in Canada and on some lifestyle strategies for reducing the risk of stroke. Prepare a poster summarizing your research results in the form of charts, graphs, and tables. Be prepared to share your findings with your class. Search for information in newspapers, periodicals, CD-ROMs, and on the Internet.

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8. The EEG has been used to legally determine death. Although the heart may continue to beat, the cessation of brain activity signals legal death. Ethical problems arise when some brain activity remains despite massive damage. Artificial resuscitators can assume the responsibilities of the medulla oblongata and regulate breathing movements. Feeding tubes can supply food, and catheters can remove wastes when voluntary muscles can no longer be controlled. The question of whether life should be sustained by artificial means has often been raised. Should a machine like the EEG be used to define the end of life? Explain your answer.

The Peripheral Nervous System 13.4

The peripheral nervous system is composed of two divisions, the sensory-somatic and the autonomic nervous system. Both of these systems are composed of sensory neurons, which run from stimulus receptors to the central nervous system (CNS), and motor neurons, which run from the CNS to muscles or organs that take action. The sensory-somatic nervous system senses and responds to external stimuli, and the autonomic nervous system responds to internal stimuli (**Figure 1**).

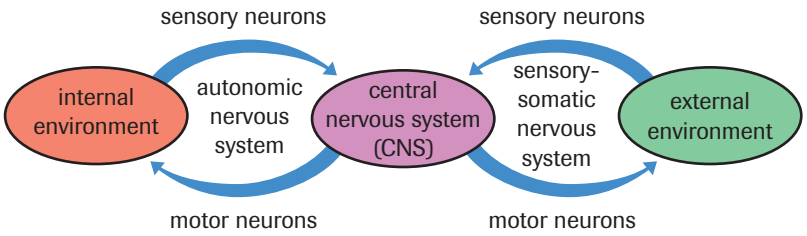

Figure 1
Both divisions of the peripheral nervous system interact with the central nervous system.

The Sensory-Somatic System

The sensory-somatic nervous system brings information about the external environment to the CNS and sends information back to the skeletal muscles. The sensory-somatic nervous system is considered to be under voluntary (somatic) control because you can, for the most part, control the movement of your muscles. However, reflex arcs, which are involuntary, also fall under the sensory-somatic nervous system.

This system is composed of 12 pairs of cranial nerves (nerves that originate in the brain) and 31 pairs of spinal nerves. Some of these nerves have only sensory neurons, others have motor neurons, and others have both sensory and motor neurons. The cranial nerves control vision, hearing and balance, taste and smell, facial and tongue movements, and muscles of the head and neck among other things. The spinal nerves innervate the skeletal muscles for the rest of the body. All our conscious awareness of our surroundings and all our actions to cope with them operate through the sensory-somatic nervous system.

The Autonomic Nervous System

The autonomic nervous system brings information about the body's internal environment to the CNS and carries signals back to regulate the internal environment. So the autonomic nervous system controls smooth muscle, cardiac muscle, the internal organs, and glands. Unlike the sensory-somatic nervous system, this control is involuntary. For example, rarely do you consciously direct your breathing movements. Blood oxygen levels are monitored throughout the body. If levels fall below the normal range, autonomic nerves act to restore oxygen levels by increasing your breathing rate and heart rate.

The autonomic nervous system also differs anatomically from the sensory-somatic nervous system. It uses two groups of motor neurons to stimulate the target effectors (muscles, organs, or glands). The first group, the preganglionic neurons, run from the CNS to a ganglion where they connect with a second group, the postganglionic neurons, which then run to the target organ, muscle, or gland.

DID YOU KNOW?

How Polygraphs Work

Lie detectors (also known as polygraphs) monitor changes in the activity of the sympathetic nervous system. One component of a lie detector, the galvanic skin response, checks for small changes in perspiration. In theory, a stressful situation, such as lying, would cause the stimulation of sympathetic nerves, which, in turn, would activate the sweat glands. Increased breathing and pulse rates are also monitored by lie detectors. Because lie detectors cannot always differentiate between lying and other stressful situations, they are not considered 100 % accurate.

sympathetic nervous system nerve cells of the autonomic nervous system that prepare the body for stress

parasympathetic nervous system nerve cells of the autonomic nervous system that return the body to normal resting levels after adjustments to stress

The autonomic system is made up of two distinct, and often opposing, units, the **sympathetic nervous system** and **parasympathetic nervous system** (**Figure 2**). The sympathetic system prepares the body for stress, while the parasympathetic system reverses the effects of the sympathetic nervous system and restores the body to normal. **Table 1**, on the next page, summarizes the effects of the autonomic nervous system. Sympathetic and parasympathetic nerves also differ in anatomy. Sympathetic nerves have a short preganglionic nerve and a longer postganglionic nerve; the parasympathetic nerves have a long preganglionic nerve and a shorter postganglionic nerve. The preganglionic nerves of both systems release acetylcholine, but the postganglionic nerve from the sympathetic system releases norepinephrine. The postganglionic nerves from the parasympathetic system release acetylcholine and nitric oxide. The sympathetic nerves

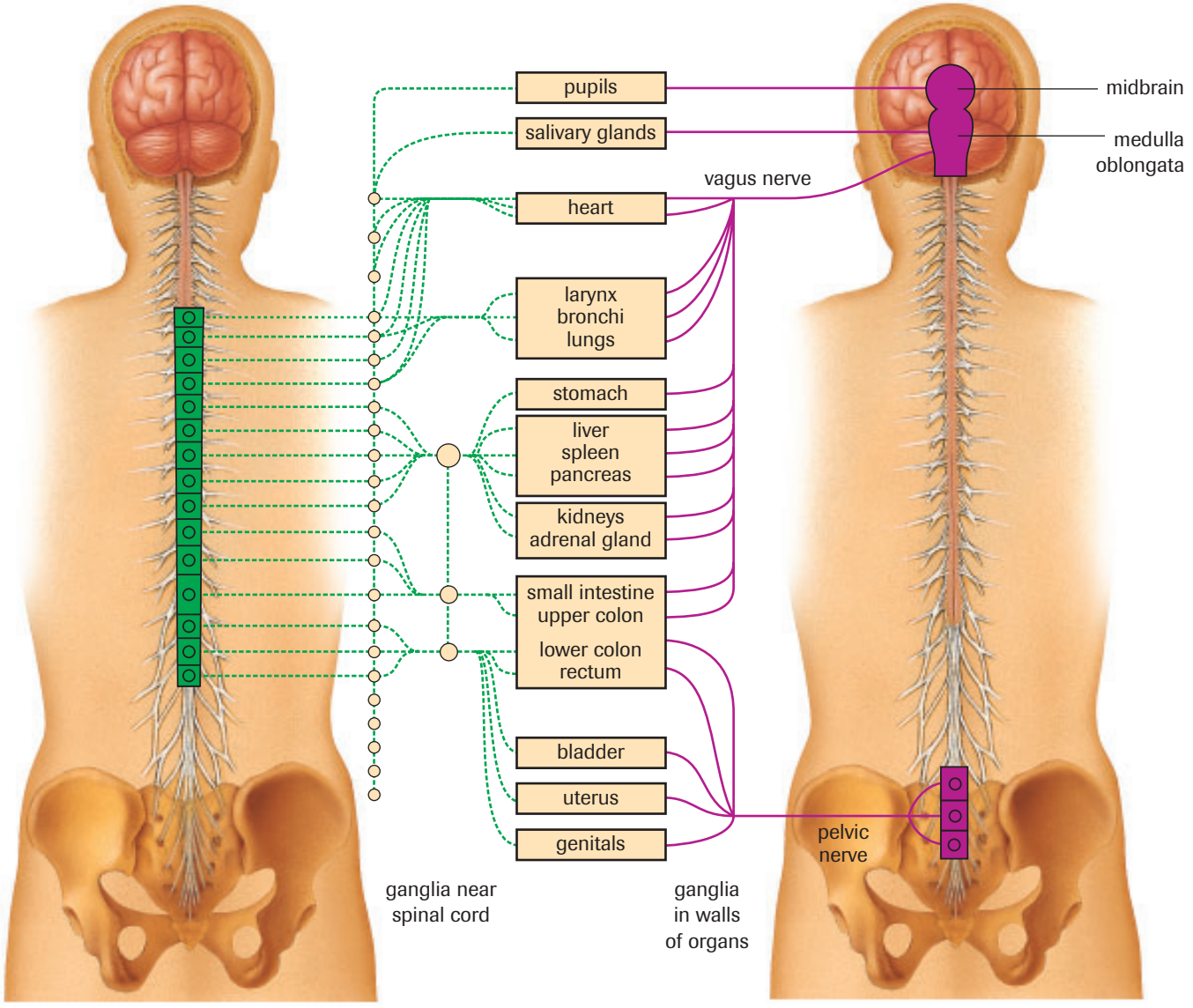

Figure 2
The sympathetic nerves are shown in green, and the parasympathetic nerves are shown in purple.

Table 1 Some Effects of the Autonomic Nervous System

Organ	Sympathetic	Parasympathetic
heart	increases heart rate	decreases heart rate
digestive tract	decreases peristalsis	increases peristalsis
liver	increases the release of glucose	stores glucose
eyes	dilates pupils	constricts pupils
bladder	relaxes sphincter	contracts sphincter
skin	increases blood flow	decreases blood flow
adrenal gland	causes release of epinephrine	no effect

CAREER CONNECTION

Chiropractor

Chiropractors treat disorders of the musculoskeletal system by manipulating the spinal column. They often work with massage therapists, physiotherapists, and physicians and may interpret X-rays, make diagnoses, and develop treatment plans.

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come from the thoracic vertebrae (ribs) and lumbar vertebrae (small of the back). The parasympathetic nerves exit directly from the brain or from either the cervical (the neck area) or caudal (tailbone) sections of the spinal cord. An important cranial nerve of the parasympathetic system is the **vagus nerve** (*vagus* meaning "wandering"). Branches of the vagus nerve innervate the heart, bronchi of the lungs, liver, pancreas, and the digestive tract.

vagus nerve major cranial nerve that is part of the parasympathetic nervous system

SUMMARY The Peripheral Nervous System

- The peripheral nervous system is made up of the sensory-somatic and the autonomic nervous systems. Together they sense and respond to external and internal stimuli.
- The autonomic nervous system consists of the sympathetic and parasympathetic systems. The sympathetic system prepares the body for stress; the parasympathetic system returns the body to a resting state.

Section 13.4 Questions

1. State the similarities and differences between the two divisions of the peripheral nervous system.
2. State the two divisions of the autonomic nervous system and compare their structures and functions.
3. What are the functions of the vagus nerve?
4. How do sympathetic and parasympathetic nerves differ from one another?
5. Many prescription drugs affect the autonomic nervous system. **Table 2** describes the action of four different drugs.
   (a) Which drug should not be taken by someone who has high blood pressure? Give reasons for your answer.
   (b) A patient who has taken too much neostigmine is admitted to hospital. What symptoms would be displayed?

Table 2 Drug Actions

Drug	Action
pilocarpine	produces effects similar to the parasympathetic nervous system
resperine	inhibits the activity of the sympathetic nervous system
ephedrine	stimulates the release of norepinephrine from postganglionic nerves
neostigmine	blocks the action of cholinesterase at synapses

INVESTIGATION 13.1

Reflex Arcs

Reflex arcs make up the neural circuit that travels through the spinal cord, providing a framework for reflex actions. Simple physical tests are used to check reflexes. In this investigation, you will observe the presence and strength of a number of reflex arcs and design an investigation about the blink reflex. Read through the investigation, then write a prediction on what will happen in each part of the procedure. Then, formulate and record a hypothesis to explain your predictions. Make sure you make clear notes of all your observations as you gather evidence for the investigation.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

Problem

What is the advantage of being able to test different reflexes?

Materials

rubber reflex hammer
penlight

Procedure

Part 1: Knee Jerk

1. Find a partner. You will act as each other's subjects.
2. Have your subject sit on a chair with his or her legs crossed. The subject's upper leg should remain relaxed.
3. Locate the position of the kneecap and find the large tendon below the midline of the kneecap.
4. Using a reflex hammer, gently strike the tendon below the kneecap.
5. Ask the subject to clench a book with both hands, then strike the tendon of the upper leg once again.

Part 2: Achilles Reflex

6. Have the subject remove a shoe. Ask your subject to kneel on a chair so that his or her feet hang over the edge of the chair. Push the toes toward the legs of the chair and then lightly tap the Achilles tendon with the reflex hammer.

Part 3: Babinski Reflex

7. Now ask the subject to remove a sock. Have the subject sit in a chair, then place the heel of the bare foot on another chair for support. Quickly slide the reflex hammer along the sole of the subject's foot, beginning at the heel and moving toward the toes.

Part 4: Pupillary Reflex

8. Have the subject close one eye for approximately 1 min. Ask him or her to open the closed eye. Compare the size of the pupils.
9. Ask the subject to close both eyes for 1 min, then open both eyes. Shine a penlight in one of the eyes.
10. Select a student with light-coloured eyes to be the subject. With at least two observers carefully watching the subject's eyes, gently stroke the fine hairs on the nape of the subject's neck.

Part 5: The Blink Reflex

11. The eye blinks when an object moves toward the eye. Design an experiment to investigate conditions that initiate the reflex. Consider any of the following questions.
    - What size of object is required to initiate the blink reflex?
    - At what speed must the object move to cause the reflex?
    - At what distance from the eye is the reflex initiated?

(a) Present your design to your teacher for approval prior to conducting your investigation.

Caution: Be careful when moving objects close to the eyes to avoid injury.

Analysis

(b) From your observations, formulate a hypothesis about the sequence of events that occur in the nervous system in each part of the procedure.

(c) How does the knee-jerk reflex change when the subject is clenching the book? Why do you think this is?

(d) What is the purpose of testing different reflexes?

(e) What conclusions, if any, can you draw from the data from your investigation of the blink reflex?

INVESTIGATION 13.1 *continued*

Synthesis

(f) Explain why the knee-jerk and Achilles reflexes are important in walking.

(g) A person touches a stove, withdraws his or her hand, and then yells. Why does the yelling occur after the hand is withdrawn? Does the person become aware of the pain before the hand is withdrawn?

INVESTIGATION 13.2

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	● Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	● Evidence	

Brain Dissection

An examination of the preserved brain of a sheep or any other mammal will provide enough similarities to be useful for structural and general functional comparisons to be made between it and the human brain. The main difference between the human and most other mammalian brains is the larger human cerebrum.

Purpose

To examine the structures of a mammalian brain and relate those structures to the functions of the human brain.

Materials

safety goggles
lab apron
latex gloves
dissecting tray
forceps
scalpel
probe
model of human brain and diagrams showing different sheep brain views

See Appendix B2 for notes on lab safety during a dissection. Take particular care when using a scalpel.

Procedure

Part 1: External Structure

1. Obtain a sheep brain, examine the dorsal, lateral, and ventral views (**Figure 1**), and identify the three major structures that are easily seen:

- The large cerebrum is composed of the two cerebral hemispheres. They form the largest part of the brain and also make up the largest part of the forebrain.
- The cerebellum is the highly convoluted structure behind the cerebrum and above the brain stem. The cerebellum is part of the hindbrain.
- The brain stem extends from the spinal cord (the cut region) through the base and part of the central interior of the brain. Because the brain stem extends the length of the brain, it includes a portion of the hindbrain, the forebrain, and all of the midbrain.

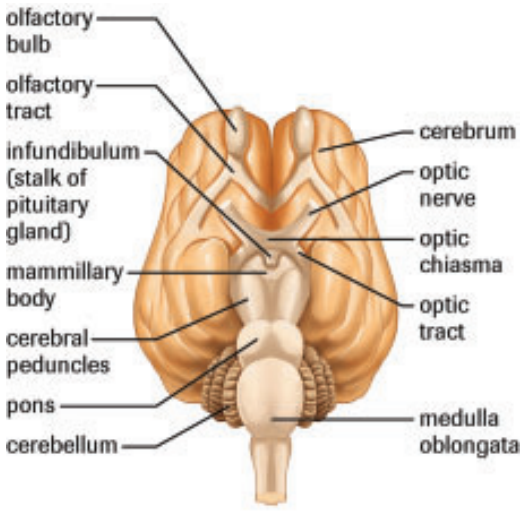

Figure 1
Sheep's brain, ventral view

INVESTIGATION 13.2 *continued*

2. Examine the cerebrum and note the convoluted appearance of its surface. A membrane called the meninges covers the surface of the cerebrum. (Depending on the preservation technique, the meninges may or may not be present.)

(a) Name and describe the functions of the three membranes that make up the meninges.

3. The convolutions are formed by the raised areas or ridges, called gyri, and the depressed areas, called fissures. The major fissures divide the important lobes of the cerebrum. The mammalian cerebrum is much more convoluted than the brains of other vertebrates, such as birds, reptiles, amphibians, and fish.

(b) What is the significance of these convolutions? How do they provide mammals with an advantage?

4. Refer to a model or diagrams of the human brain to help you locate the corresponding fissures and lobes of the sheep cerebrum. Note any differences and similarities in the cerebrums.
   - The longitudinal fissure divides the two cerebral (right and left) hemispheres.
   - The central fissure extends from the top of each cerebral hemisphere to the lateral fissure.
   - The parieto-occipital fissure is not visible externally, but is found near the back of the cerebrum deep in each cerebral hemisphere.
   - The frontal lobe is in front of the central fissure and the parietal lobe is behind this fissure, extending to the region of the parieto-occipital fissure.
   - Behind the parieto-occipital fissure is the occipital lobe.
   - Below the lateral fissure and extending to the occipital lobe is the temporal lobe.

(c) List the cerebral lobes and describe the major human functions located in each. Gently move the cerebral hemispheres apart to expose the corpus callosum.

(d) Describe the function of the corpus callosum.

5. Locate the highly convoluted cerebellum, which lies posterior to the cerebral hemispheres. Compare the cerebellum of the sheep brain with a model or diagrams of the human brain. Note that the sheep brain is not divided longitudinally, as is the human cerebellum.

(e) What is the function of the cerebellum?

6. Examine the ventral surface of the sheep brain and locate the medulla oblongata, which begins where the spinal cord widens, just below the cerebellum. The medulla oblongata contains regions where motor nerves from the right side of the cerebrum cross over to the left side of the spinal cord, and vice versa. Some sensory nerves travelling to the brain also cross over in the medulla, and others cross over where the nerve enters the spinal cord.

(f) What centres that control vital autonomic functions are located in the medulla oblongata?

7. While holding the occipital lobes, gently pull down and back on the cerebellum. In the cavity toward the centre of the brain a small, bulbous mass will be seen. This is the pineal gland of the forebrain, which secretes the hormone melatonin. The pineal gland has nerve connections with the eyes. Melatonin regulates reproductive functions related to light and changes in the seasons, marked by the amount of daylight. The precise role of melatonin and the pineal gland and how they regulate biological rhythms associated with reproduction in humans is uncertain.

(g) Research the role of melatonin and the pineal gland in their regulation of biological rhythms in other vertebrates.

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8. Just below the pineal gland are four rounded structures of the midbrain called the corpora quadrigemina. The two upper structures carry nerve impulses from the eyes and are involved with reflex responses to visual stimuli. The lower two structures relay impulses from the ears to the auditory areas of the cerebrum.

9. Examine the ventral surface of the brain. Moving forward from the spinal cord, note that just in front of the medulla oblongata is a rounded structure called the pons.

(h) What is the function of the pons?

Anterior to the pons are the rounded cerebral peduncles, which carry nerve tracts to and from the medulla oblongata and the cerebral hemispheres. The mammillary body is a rounded structure in front of the cerebral peduncles and below the hypothalamus. In the sheep brain, the mammillary body is a single structure, whereas in humans it is double. The mammillary body is a relay station for olfactory neurons.

INVESTIGATION 13.2 *continued*

(i) Describe the functions of the hypothalamus.

Below the hypothalamus and in front of the mammillary body is the infundibulum, the stalk to which the pituitary gland is attached. The pituitary gland may not be present, as it is sometimes broken off during preparation of the brain.

10. The optic chiasma forms an X in front of the infundibulum.

(j) Explain the significance of the optic chiasma in relation to the right and left retinas and the right and left occipital lobes.

Locate the olfactory bulbs in front of the optic chiasma, at the base of the frontal lobes of the cerebrum.

(k) Describe the function of the olfactory bulbs.

Part 2: Internal Structure

11. Observe the internal view (**Figure 2**) of a sheep brain that has been dissected in the sagittal plane. If the brain has not already been dissected, use your scalpel to cut vertically down the midline of the brain. Locate the following structures that were seen in the dorsal and ventral views of the whole brain: cerebrum, corpus callosum, cerebellum, medulla oblongata, spinal cord; pineal gland, corpora quadrigemina; pons, cerebral peduncle, mammillary body, infundibulum, optic chiasma, and olfactory bulb.

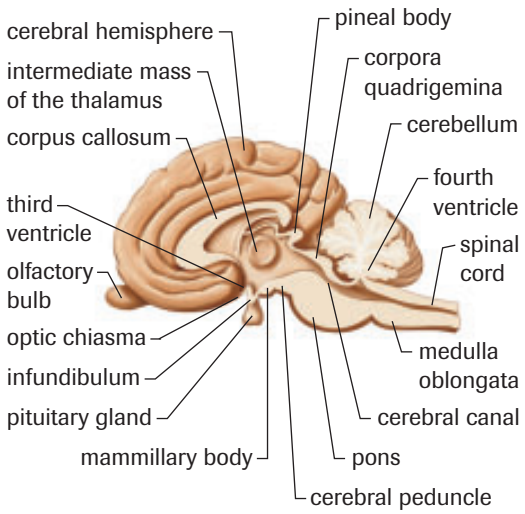

Figure 2
Sheep's brain, internal view

12. Note the difference in colour of the outer and inner regions of the cerebellum. Note also how this colour difference follows the convolutions. This is also characteristic of the cerebrum.

(l) Explain the significance of the difference in colour and its relationship to the convolutions.

(m) Explain why the corpus callosum is only one colour.

13. Locate the four ventricles of the brain. These ventricles develop from an enlargement of the cavity in the embryonic neural tube. The ventricles are filled with cerebrospinal fluid, which also surrounds the brain and the spinal cord beneath the meninges.

(n) Describe the composition of the cerebrospinal fluid.

The two lateral ventricles (the first and second ventricles) extend mostly into the parietal lobe and partly into the frontal and occipital lobes of the cerebral hemispheres, beginning from a region beneath the corpus callosum. Insert a blunt probe into the small opening below the corpus callosum to explore one of the lateral ventricles. A thin membrane on the surface of each ventricle contains a network of capillaries called the choroid plexus. These membranes and the choroid plexus capillaries produce the cerebrospinal fluid. This fluid drains from the lateral ventricles into the third ventricle, which is between the right and left masses of the thalamus. The thalamus is above the mammillary body and the hypothalamus. The hypothalamus forms the floor of the third ventricle. The third ventricle drains posteriorly through a narrow canal above the cerebral peduncle. This canal enlarges between the medulla oblongata and the cerebellum to form the fourth ventricle. Continuing posteriorly, the fourth ventricle forms a narrow canal called the central spinal canal. Where this canal begins is considered to be the beginning of the spinal cord. The cerebrospinal fluid also flows from the fourth ventricle along the dorsal surface of the spinal cord and around to its ventral surface. From the ventral surface it then begins to flow anteriorly until it reaches the brain. As the cerebrospinal fluid flows over the brain, it is reabsorbed into blood capillaries in the arachnoid layer of the meninges.

(o) Describe the functions of the ventricles and the cerebrospinal fluid.

Chapter 13 SUMMARY

Outcomes

Knowledge

- describe a neuron and myelin sheath, explaining the formation and transmission of an action potential and the transmission of a signal across a synapse and the main chemicals and transmitters involved (13.1, 13.2)
- identify structures of the central and peripheral nervous systems and explain their functions in regulating the voluntary (somatic) and involuntary (autonomic) systems, (13.1, 13.3, 13.4)
- describe the organization of neurons into nerves and simple reflex arcs (13.1)

STS

- explain that scientific knowledge and theories develop through hypotheses, collection of experimental evidence and by providing explanations (13.1)
- explain that scientific investigation includes analyzing evidence and providing explanations based on scientific theories and concepts (13.2)
- explain that the goal of technology is to provide solutions to practical problems (13.3)

Skills

- conduct investigations and record data by: investigating the physiology of reflex arcs (13.1); observing neurons and synapses (13.3); and observing a mammalian brain and identifying structures (13.3)
- analyze data and apply concepts (13.1, 13.3)
- work as members of a team (all)

Key Terms

13.1

central nervous system (CNS)
peripheral nervous system (PNS)
glial cell
neuron
dendrite
axon
myelin sheath
Schwann cell
nodes of Ranvier
neurilemma
sensory neuron
sensory receptor
ganglion
interneuron
motor neuron
effector
reflex arc

13.2

action potential
resting potential
facilitated diffusion
gated ion channel
sodium-potassium pump
active transport
polarized membrane
depolarization
repolarization
hyperpolarization
refractory period
saltatory conduction
threshold level
all-or-none response
synapse
neurotransmitter
presynaptic neuron
postsynaptic neuron
acetylcholine
cholinesterase
summation
addiction

13.3

meninges
cerebrospinal fluid
cerebrum
cerebral cortex
corpus callosum
thalamus
hypothalamus
olfactory bulb
cerebellum
pons
medulla oblongata

13.4

sympathetic nervous system
parasympathetic nervous system
vagus nerve

MAKE a summary

1. Construct a mind map of the nervous system by linking key terms. Begin with **Figure 1**, page 408, in Section 13.1.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 13
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

Mirror Neurons

A recently discovered system in the brain may help explain why we humans can get so worked up watching other people. Watch this *NOVA* video to find out some explanations of this phenomenon.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The nervous and endocrine systems are similar, in that they both
   A. regulate body movement
   B. have prolonged effects on target organs
   C. respond to changes in equilibrium to maintain homeostasis
   D. respond to changes in the external environment, but do not respond to changes in the internal environment

2. The primary function of the myelin sheath is to
   A. supply nutrients to the axon
   B. increase the speed at which nerve impulses travel
   C. conduct active transport of potassium ions
   D. regulate the diffusion of sodium ions across the synapse

Use the following information to answer questions 3 and 4.

Figure 1 shows a reflex arc. The neurons that make up the arc are labelled with roman numerals.

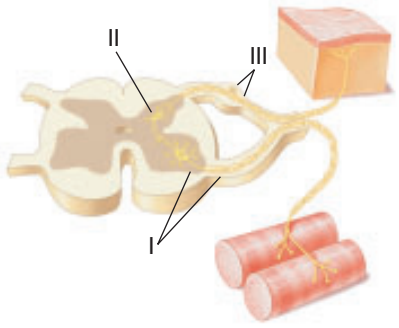

Figure 1

3. If neuron I were severed,
   A. the sensory receptor would detect touch, but the muscle would not contract
   B. the muscle would still be capable of contracting, but sensory information would not be relayed to the CNS
   C. the reflex arc would not work because sensory information is not received by the CNS
   D. it would be impossible for the information received by the sensory neuron to travel to the brain

4. The order in which an impulse travels along the reflex arc is
   A. I, II, and III
   B. II, I, and III
   C. III, II, and I
   D. III, I, and II

5. An impulse can move from one neuron to an adjacent neuron because
   A. the axon of one neuron always touches the axon of the adjacent neuron
   B. dendrites of one neuron always touch the axon of the adjacent neuron
   C. chemical transmitters are released from the dendrites of one neuron and diffuse to the axon terminal of the adjacent neuron
   D. chemical transmitters are released from the axon terminal of one neuron and diffuse to the dendrites of the adjacent neuron

Use the following information to answer questions 6 and 7.

Figure 2 shows the change in the membrane potential of a neuron as it undergoes an action potential.

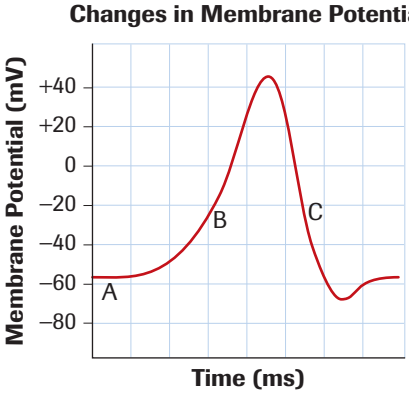

Figure 2

6. The area of the graph that indicates the opening of Na^+ ion channels and the diffusion of Na^+ ions into the nerve cells is
   A. area A, which represents polarization of the membrane
   B. area B, which represents depolarization of the membrane
   C. area C, which represents repolarization of the membrane
   D. areas B and C, which represent depolarization of the membrane

7. Repolarization occurs in
   A. area B because more K^+ ions enter the cell than Na^+ leave
   B. area B because more Na^+ ions enter the cell than K^+ leave
   C. area C because of diffusion of K^+ ions out of the axon
   D. area C because of diffusion of Na^+ ions out of the axon

8. A stroke results in a loss of speech, difficulty in using the right arm, and an inability to solve mathematical equations. Which area of the brain is damaged?
   A. left cerebellum
   B. right cerebellum
   C. left cerebral hemisphere
   D. right cerebral hemisphere

9. NR Place the following events involved in nerve transmission across a synapse in the order in which they occur. (Record all four digits of your answer.)
   1. Cholinesterase attaches to acetylcholine.
   2. Acetylcholine is released from the vesicles in the presynaptic neuron.
   3. The electrochemical impulse reaches the end plate of the presynaptic neuron.
   4. Sodium channels are opened along the postsynaptic neuron.

10. NR In **Figure 3**, which number represents the segment of the neuron that is: depolarized, polarized (resting membrane), repolarized (refractory period), and more permeable to Na^+ ions? (Record all four digits of your answer.)

_____	_____	_____	_____
depolarized	polarized	repolarized	more permeable to Na^+ ions

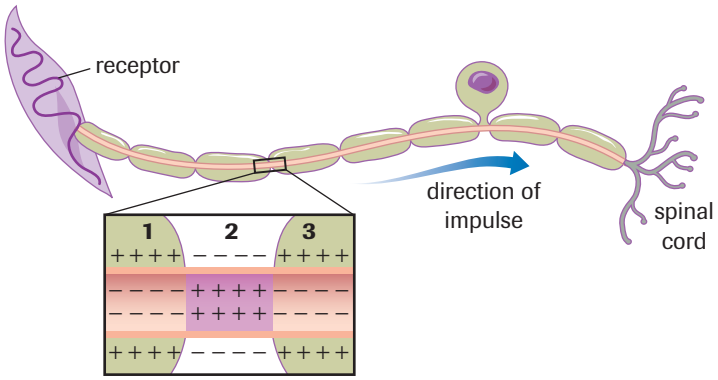

Figure 3
Myelinated neuron

11. NR From the list, identify the statements about the synapse that are correct. (Record all four digits of your answer in lowest-to-highest numerical order.)
   1. Nerve impulses speed up as they cross the synapse.
   2. Synapses occur only between two neurons.
   3. Destruction of the synaptic vesicles in neuron #1 will prevent depolarization in neuron #2.
   4. Neurotransmitters released from neuron #1 attach to the postsynaptic membrane of neuron #2.
   5. Neurotransmitters diffuse across the synapse.
   6. All neurotransmitters cause the depolarization of the postsynaptic membrane.
   7. Neurotransmitters from neuron #1 are destroyed by enzymes.

Part 2

12. Use what you have learned about threshold levels to **explain why** some individuals can tolerate more pain than others.

13. In **Figure 4**, the neurotransmitter released from neuron X causes the postsynaptic membrane of nerve Y to become more permeable to sodium. However, the neurotransmitter released from nerve W causes the postsynaptic membrane of nerve Y to become less permeable to sodium but more permeable to potassium. **Explain why** the stimulation of neuron X produces an action potential in neuron Y, but the stimulation of neuron X and W together fails to produce an action potential.

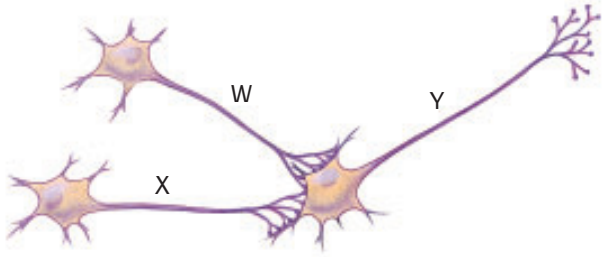

Figure 4
Nerve pathway

14. Botulism (a toxin produced by bacteria that causes food poisoning) and curare (a natural poison) inhibit the action of acetylcholine. **Describe** the symptoms you would expect to find in someone exposed to botulism or curare. **Explain** the symptoms.

15. A patient complains of losing his sense of balance. A marked decrease in muscle coordination is also mentioned. **Identify** which area of the brain a physician might look at for the cause of the symptoms.

Use the following information to answer questions 16 and 17.

A nerve cell that synapses in a muscle is stimulated by electrical current. The strength of the stimulus is increased and the force of muscle contraction is recorded. The results are recorded in **Table 1**.

Table 1 Stimulus Strength and Force of Muscle Contraction

Trial	Strength of stimulus (mV)	Force of contraction of muscle (N)
1	0	none
2	10	none
3	20	4
4	30	not measured

16. **Predict** the force of muscle contraction in trial 4. Give your reasons. DE

17. **Identify** the threshold level from the experiment. DE

Use the following information to answer questions 18 and 19.

Three different neurons synapse on a single neuron, as shown in **Figure 5**. The experimental data is recorded in **Table 2**.

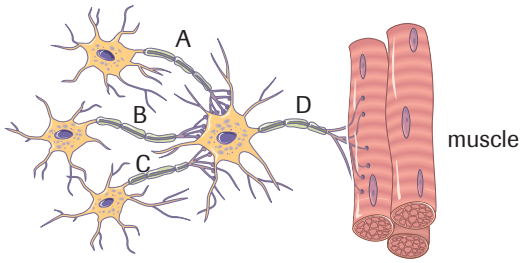

Figure 5

Table 2 Effects of Stimulating Neurons A, B, and C

Neuron stimulated	Effect on muscle
A	contraction
A and B	no contraction
B	no contraction
A and C	contraction
C	no contraction
B and C	no contraction

18. From the experimental data, **infer** which neuron releases an inhibitory neurotransmitter. DE

19. **Explain** the principle of summation using the experimental data. DE

20. During World War I, physicians noted a phenomenon called "phantom pains." Soldiers with amputated limbs complained of pain or itching in the missing limb. Use your knowledge of sensory nerves and the central nervous system to **explain** this phenomenon.

21. Scientists continue to look for chemical factors that both stimulate and inhibit the growth of new nerve cells. One such factor is myelin-associated glycoprotein (MAG), which is abundant in the myelin sheath of neurons in the central nervous system, but is scarce in the myelin of peripheral nervous system neurons. Write a unified response addressing the following aspects of research into MAG: DE
    - **Predict** whether MAG is a growth stimulator or growth inhibitor? **Justify** your answer.
    - **Why** might scientists be interested in developing drugs that would turn on or turn off MAG?

22. People with Parkinson's disease have low levels of the neurotransmitter dopamine. Researchers have been able to coax rat embryonic stem cells to develop into dopamine neurons. When these neurons were implanted into rats with a rodent version of Parkinson's, the characteristic tremor of the disease disappeared. Conduct research to **identify** the latest information concerning treatment of Parkinson's disease.

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23. For hundreds of years, people in China have believed that drinking herbal tea can improve one's memory. Researchers have isolated a compound from the tea that inhibits the action of cholinesterase. The compound, called huperzine A, is believed to be the active ingredient. Researchers are now exploring whether huperzine A affects symptoms of Alzheimer's disease. Write a unified response addressing the following aspects of huperzine A and Alzheimer's disease: DE
    - **Why** are researchers exploring the use of huperzine A for Alzheimer's patients?
    - **Why** do you think that some Western scientists have been reluctant to research medicinal effects of herbal teas?
    - **How** do you think the research into herbal teas will be received once the action of hyperzine A is known?

24. Individuals with spinal cord injuries often report loss of sensation and muscle paralysis. Recently, researchers have found that Id proteins, proteins in cancer cells which promote tumour growth, may be used to help re-grow damaged axons in the CNS. Investigate Id proteins and their potential to regenerate axons.
    (a) **Explain why** a person with a spinal cord injury might experience a loss of sensation.
    (b) **Describe** the significance of using Id proteins to stimulate the repair of damaged axons.
    (c) **Why** is it unlikely that the Id proteins might cause brain cancer if introduced into neurons?

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25. Use what you know about the transmission of nerve impulses to **hypothesize** (formulate a hypothesis) about how local and general anaesthetics work.

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